ARANUIAN

POLLEN DIAGRAMS FROM MONTANE CANTERBURY

NEW ZEALAND

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ABSTRACT

Detailed site histories are developed from pollen analyses at six sites in three areas of montane Canterbury:- upper Rakaia Valley, Mt. Somers, Lake Sumner.

A post-glacial (Aranuian) vegetational and climatic history for central montane Canterbury is developed from these site histories and pollen analyses published from other areas. The site histories relate broadly to existing knowledge, but it is shown that pollen diagrams from montane areas may not be taken as being directly representative of the regional vegetation.

Forest in montane Canterbury became widespread in the upper Rakaia Valley 10 000 years ago. The subsequent spread of beech forest (species of the *Nothofagus fusca* pollen group) in montane Canterbury occurred about 6 000 years ago in the Waimakariri and Hurunui catchments; more than 4 500 years ago in the Harper tributary of the Rakaia River; and about 1 000 years ago in the vicinity of Prospect Hill in the upper Rakaia Valley. The isolated occurrence of silver beech (*N. menziesii*) in the Lake Stream tributary of the Rakaia River has a probable history of about 8 000 years, and at Prospect Hill, a local history of 2 000 years. Beech forests of the Hurunui catchment originated from a northern mixed beech source, while the beech forests of the Waimakariri and Rakaia catchments, and Mt. Somers, originated mainly from mountain beech (*N. solandri* var. *cliffortioides*) sources, scattered most probably in the foothills of the central Canterbury Alps.

Present evidence suggests that there was a marked

improvement in climate 10 000 years ago from cold early Aranuian conditions. It is thought that climatic conditions were most equable between 10 000 and about 6 000 yr B.P. when precipitation was higher than at present. Conditions deteriorated at about 6 000 yr B.P. becoming drier and less equable, approaching present conditions.

Pollen and charcoal evidence of European, Polynesian, and prehistoric fires in the study areas contributes to the history of man-caused and natural fires in Canterbury. Polynesian fires in the Upper Rakaia - Lake Heron - Mt. Somers region are seen as the coup de grâce in a long established history of decline of montane podocarp forest there.

CHAPTER 1

INTRODUCTION

This study is broadly concerned with the establishment and post-glacial history of the montane forests of Canterbury, New Zealand, during the Aranuian Interglacial period: an interval which comprises the last 14 000 years and which begins with the retreat of ice from the Otira Glaciation (Suggate, 1961, 1965).

The aims of the study are:-

1. To further the knowledge of the Aranuian vegetational and climatic history of Canterbury with pollen diagrams from the Lake Heron and Lake Sumner districts;

and to investigate the following points of especial interest in montane Canterbury:-

2. The date of forest expansion following deglaciation.
3. The timing of *Nothofagus* (beech) forest expansion.
4. The origin and history of one of the isolated *Nothofagus menziesii* (silver beech) stands in Canterbury.
5. The fire history of the study areas.

1. The broad history of the development of post-glacial vegetation in the South Island has been established well enough to show that the patterns of development have been complex (Cranwell & von Post, 1936; Moar, 1971). In

montane Canterbury (Fig. 1.1) studies of Aranuian vegetation history have been centred in the Cass district. Several pollen sites there have established a grassland-shrubland-forest sequence broadly similar to, but different in detail from, the pattern of vegetation development elsewhere in the South Island (Lintott, 1963; Moar, 1971, 1973b; Lintott & Burrows, 1973) including lowland Canterbury (Moar, 1970a, 1973b). With the exception of a pollen diagram from the Harper River in the Rakaia catchment to the south of Cass (Moar, 1973a), no other pollen analytical work has been published on the montane forests east of the Southern Alps (the Main Divide) in Canterbury although knowledge of their former extent and recent history is increasing (e.g., Molloy & Cox, 1972; Moar & Lintott, 1977). The inter-montane basins containing Lakes Heron and Sumner lie respectively to the south and north of the Cass inter-montane basin and different forest types predominate in each of the three areas.

These general factors (unstudied territory, different forests, locations straddling the much studied Cass district) and the presence of promising coring sites, made the new localities potentially interesting for further study of the Aranuian history of Canterbury forests.

2. In the South Island, radiocarbon dated pollen diagrams from Dunedin (McIntyre & McKellar, 1970) and North Westland (Moar, 1971) have shown that the early Aranuian expansion of forest following deglaciation occurred about 10 000 years ago in those areas. The spread of forest may have been a synchronous event but the present dates are as yet

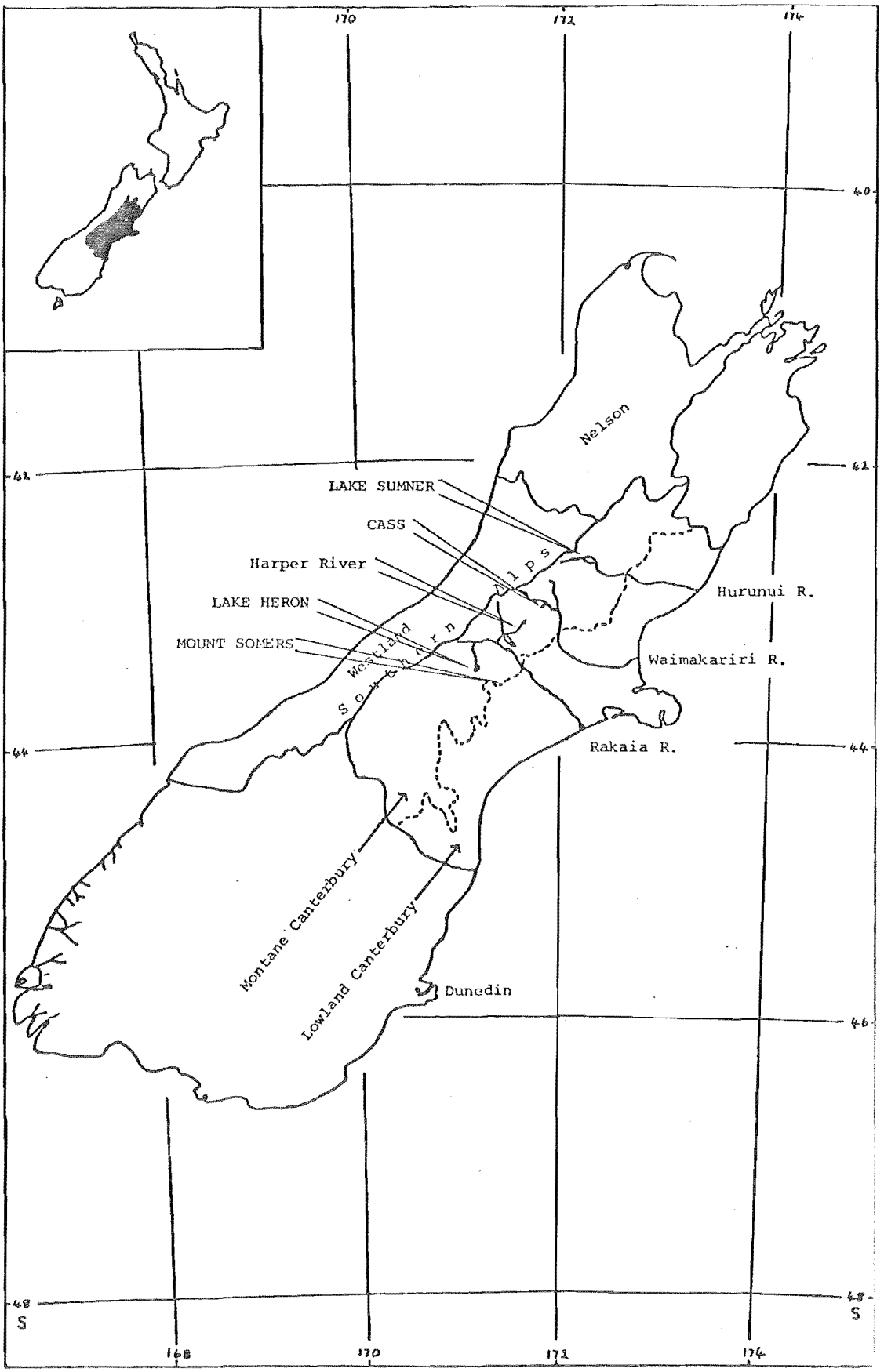


Figure 1.1 Canterbury, South Island, New Zealand; showing localities mentioned in text.

too few to support such an assumption with any degree of certainty. Dates of early Aranuian forest expansion in Canterbury were sought to help establish the timing of this event throughout the South Island.

3. West of the Main Divide several pollen sites in North Westland have shown the spread of the northern beech forest there to have been a diachronous event, beginning in Nelson and occurring progressively southward over a period of some 5 000 years (Moar, 1971). It was hoped to learn something of the metachroneity of this event east of the Main Divide in Canterbury. The two study areas and Cass comprise a line of sites in montane Canterbury within the northern beech forest and approaching its southern limits.

4. One of the puzzling aspects of plant distribution in Canterbury is the anomalous occurrence of small isolated stands of silver beech. In the Lake Heron study area sites were located close to one of these silver beech stands, in order to test the hypothesis that their distribution was a relict distribution representing positions of survival during the Otira glaciation.

5. Canterbury has had an extensive fire history. Evidence from charcoals, sub-fossil plant remains, and buried soils, show that fires have occurred at periods throughout Aranuian time in lowland and montane Canterbury. The abrupt drop in beech pollen frequencies evident in most pollen diagrams from Canterbury reflects the major destruction of forest by fire in Polynesian times. Studies in the Cass district are building a detailed history there (Molloy, 1977) and it was hoped to obtain charcoal and pollen evidence of similar fires in the study areas.

The substance of this study is summarised in the following tables:

1. Site Histories:

2. Vegetation History:

3. Climate History:

4. Early Aranuian Forest Expansion

The detailed interpretations of pollen data, leading to the six site-histories, are presented in chapters 6-11. In the discussion, chapter 12, the results of these detailed interpretations are used, with other available evidence, to synthesize an appreciation of the aims of this study as already outlined.

CHAPTER 2

SETTING

2.1 PHYSIOGRAPHY

2.1.1 Geomorphology

The topography of Canterbury (Fig. 2.1) results from its geological history (Table. 2A). The shape of the present landscape has been largely determined by the late Tertiary - early Pleistocene Kaikouran orogeny, during which the present mountain ranges were uplifted and the Banks Peninsula volcanoes built; and the subsequent modification by glacial, fluvial, and mass wasting processes which were active during the climatic fluctuations of the late Pleistocene.

The mountain ranges of Canterbury are of youthful form with jagged ridges and with peaks up to 2 000 - 2 500 m altitude. They are part of the Southern Alps (the "Main Divide") which form the central axial mountain system of the South Island. The montane valleys and tributaries of the main rivers are fluvially modified glacial valleys. Tectonic control is sometimes evident. Most lakes and tarns have a glacial origin and glacial landforms and periglacial features originating from the most recent glaciation (Otira) are common. Main rivers and tributaries flow in braided courses on wide shingle beds and the large alluvial fans that occur at the foot of most valley walls are a distinctive feature. Today, glaciation is most

Figure 2.1 Relief map, South Island.

Table 2A. Major geological events in Canterbury (from Gage, 1969).

Era	*Period*		*Million years b.p.*
Quaternary	Holocene ("Recent")	Final post-glacial rise of sea-level; peat, silt and shell-beds under Christchurch deposited; erosional valleys on Banks Peninsula volcano drowned to form harbours and bays.	0 — 0.01
	Late Pleistocene	Great oscillations of climate; during cold phases glaciers advance far down valleys, wear down divides and change valley-pattern; moraines and thick gravel deposits formed, including Canterbury Plain; during interglacial warm intervals, glaciers decline, streams carve terraces, the sea stands high and forms raised beaches and cliffs above present sea-level. Wind-blown "loess" silts accumulate during glacial episodes.	?3
	Early Pleistocene, Pliocene	Prolonged eruptions (mainly basaltic) build Banks Peninsula volcanoes. Crustal movements and elevation accelerate: withdrawal of sea from region; mountain chains gain elevation ("Kaikoura Movements").	13
Tertiary	Miocene	Formerly unified region breaks into smaller crustal segments, some rising, some sinking; eastern Canterbury still mainly under shallowing seas; islands rising to the west; local volcanic activity in mid-Canterbury.	25
	Oligocene	Maximum spread of sea; probably all of Canterbury region submerged; main limestone deposits formed; submarine volcanoes active over wide area.	36
	Eocene Late Cretaceous	Sea spreads slowly over peneplain from south and east; coal-forming peat accumulates in coastal fringing swamps and is buried under sand and silt deposits as the sea advances.	100
Mesozoic	Middle Cretaceous	Mountainous relief slowly destroyed by erosion, reduced to a low, undulating "peneplain", mantled with a deep soil, which extended probably throughout Canterbury and far beyond.	120
	Early Cretaceous	Vigorous compression and uplift of sediments in geosyncline; mountain ranges develop ("Rangitata Movements")	135
	Late Jurassic	Geosyncline trough becomes narrower; islands appear; volcanoes active.	170
	Early Jurassic Triassic	Canterbury region wholly under the sea; part of "New Zealand Geosyncline" oceanic trough in which debris eroded from land most likely to the westward accumulated rapidly to form the basement rocks. Submarine volcanic activity within the trough.	230
Late Palaeozoic	Permian		?

extensive in the Mt. Cook region of South Canterbury where peaks rise to 3 700 m. Valley glaciers there descend to about 500 m altitude and small glaciers occur in the heads of most major valleys north to the Waimakariri valley.

2.1.2 Rock type

The rock type predominating in the Canterbury mountains is the Permian - early Jurassic sandstone suite of the Torlesse group. This group comprises a range of grey, well indurated sandstones and siltstones of varied grain-size and structure, and hard black mudstones. The Torlesse sandstones are accompanied in some localities by conglomerate, red chert, basaltic lava and tuffs, some trachyte and rhyolite, and may be intruded in places by syenite and gabbro. Other rock types present are the limestones, greensands and coalmeasures of Cretaceous-Tertiary age, found preserved in structural basins within the mountains and on the lower flanks of some of the foothill ranges facing the plains.

2.1.3 Processes

Mass movement processes, freeze thaw effects, solifluxion and soil creep, are active on steep unvegetated upper slopes, and the usually well jointed sandstones contribute much material to the fluvial processes predominant on the lower slopes and valley floors.

Recent cultural interference has accelerated natural steepland erosion in the mountains. Possums (*Trichosurus vulpecula*), red deer (*Cervus elaphus*), chamois (*Rupicapra*

rupicapra), and thar (*Hemitragus jemlahicus*), introduced by European settlers have led to a decline in the richness of alpine vegetation and have affected its stability. In the frontal ranges especially, sawmilling and accidental forest fires during the European settlement period (1860s - 90s), and an only recently discontinued high country agricultural policy of pasture management by repeated 'burn-offs', compounded by overgrazing, has opened up much alpine grassland to serious erosion - the 'streams of grey screes flowing down Canterbury hillsides'.

2.1.4 Soils

The broad pattern of Canterbury soils is published in "Soils of South Island, New Zealand", Soil Bureau Bulletin, No. 27 (1968). Vucetich (1969) has further discussed the soils of Canterbury and Cutler (1977) provides a more detailed analysis of the mountain soils in his description of the soils of the Cass district.

The soils of Canterbury, and of the high country in particular, are, with local exceptions, closely related due to their common parent rock - the 'greywacke' sandstones of the Torlesse group. However, despite similarities in general appearance they vary markedly in structure. This is because any soil is the product of a complex of inter-acting soil forming processes acting (in the Canterbury high country) on different states of the parent greywacke material (e.g., Fig. 2.2), and being subject to the variable influences of vegetation, slope, and climate (macro and micro). Added to the 'normal' soil development process

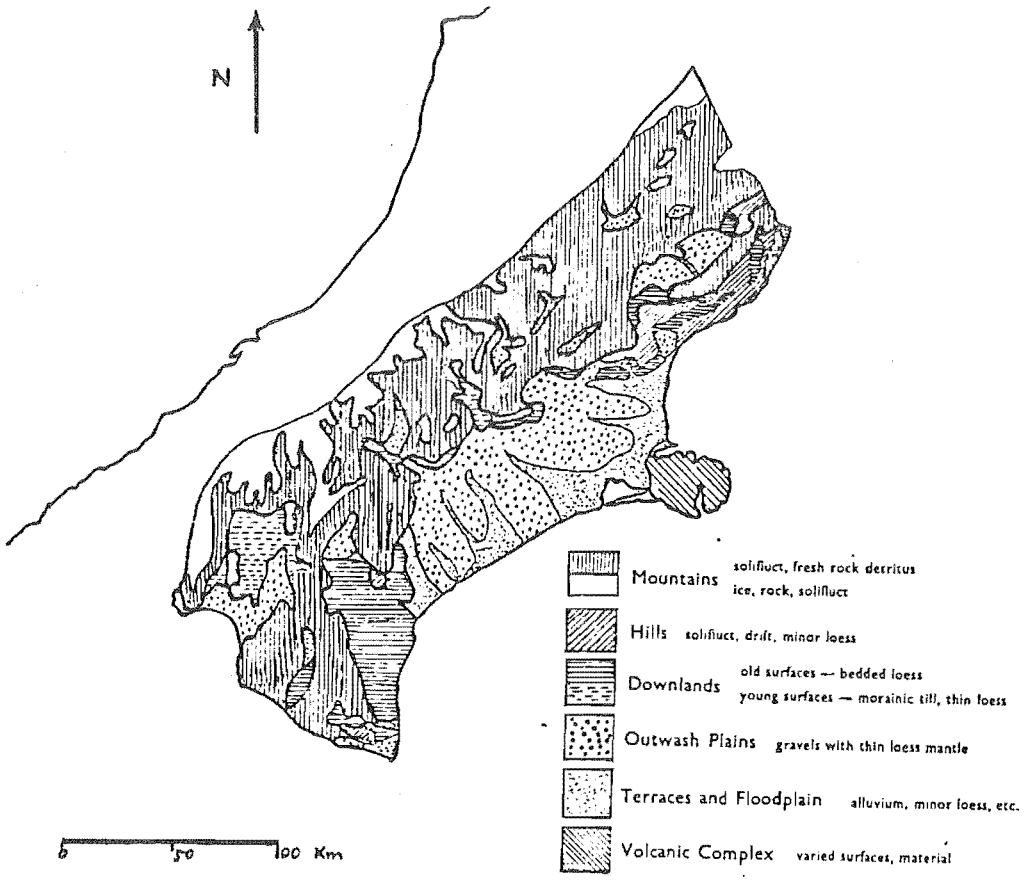


Figure 2.2. Canterbury land forms and soil materials (from Vucetich, 1969).

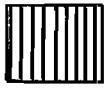
Table 2B. A chronosequence of soils developed from greywacke detritus in the Cass district (from Cutler, 1977)

Stage	New Zealand Classification*	Map Unit
Stage 1	Recent soils	Tasman Set
Stage 2	Intergrade between recent soil and high country yellow-brown earth	
Stage 3	Moderately to strongly leached high country yellow-brown earth	Mesopotamia Set
Stage 4	Strongly to very strongly leached high country yellow-brown earth.	Craigieburn, Cass Sets
Stage 5	Weakly podzolised high country yellow-brown earth	Bealey Set
Stage 6	High country podzols	Katrine Set
Stage 7	High country gley-podzol	Lewis Set

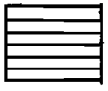
* The classification and terminology are basically after Taylor & Pohlen (1962)

Figure 2.3. Soils of Montane Canterbury. Recent Soils (alluvial) occur on river terraces, floodplains, and young fans. The Upland and High Country Yellow-brown Earths are the most common soils of montane Canterbury; the Lowland Yellow-brown Earths lie in a broad belt along the foothills. In areas of high precipitation as in the headwaters of the major rivers close to the Main Divide heavy precipitation results in the occurrence of the High Country Podzolised Yellow-brown Earths and Podzols. Alpine Steepland Soils (rock, scree and skeletal alpine soils) occur on the tops of the higher ranges. (adapted from Soil Bureau Staff, 1968).

Key to Soils

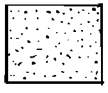


Lowland Yellow-brown Earths



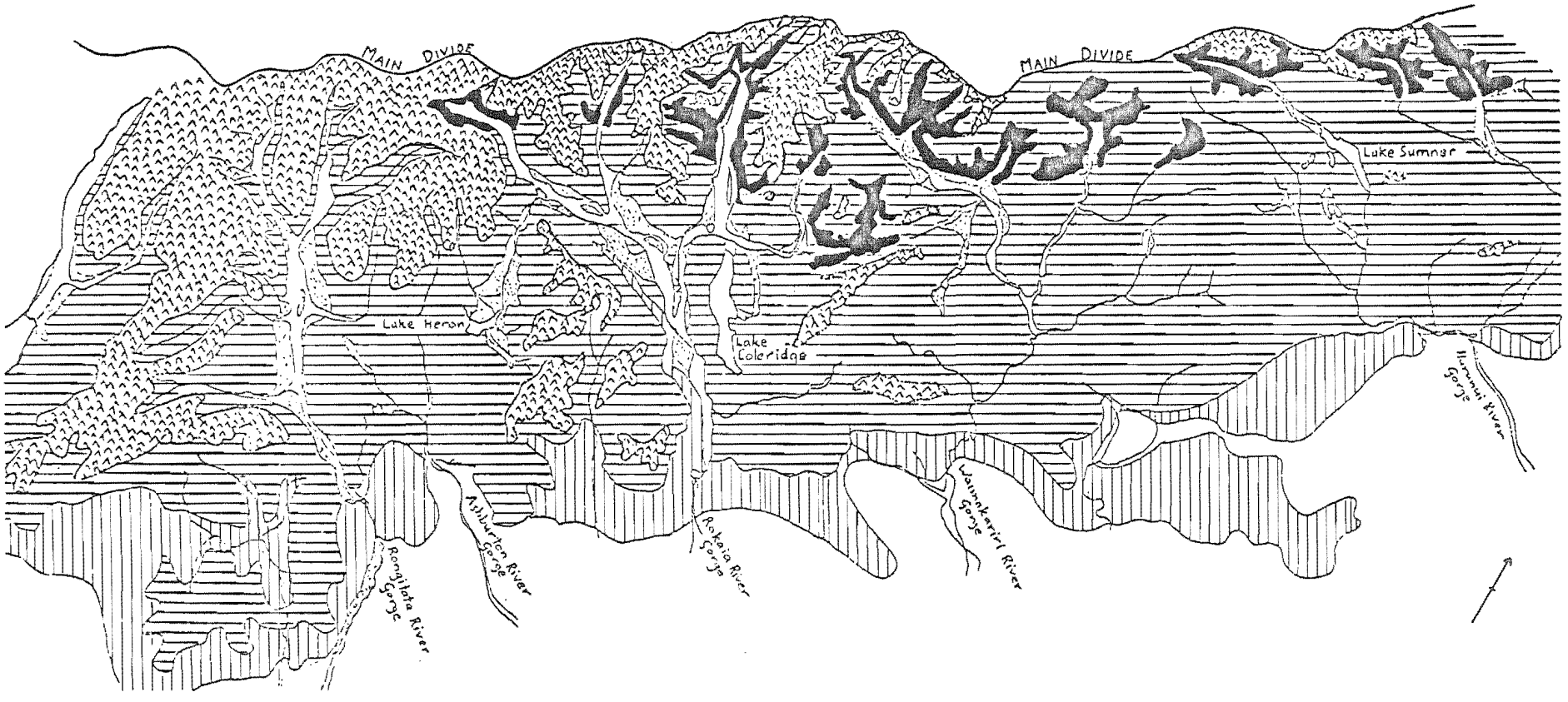
Upland and High Country Yellow-brown Earths

Upland and High Country Podzolised Yellow-brown Earths and Podzols



Recent Soils

Alpine Steepland Soils


MAIN DIVIDE
MAIN DIVIDE
Lake Sumner
Lake Heron
Lake Coleridge
Hurunui River Gorge
Waimakariri River Gorge
Rakaia River Gorge
Ashburton River Gorge
Rangitata River Gorge

occurring with time are modifications imposed by erosion and deposition processes and also such historical factors as fire, and changes in vegetation and climate. The end result is the apparent profusion of mapped soil types each named from type areas.

Put very simply the high country soils may be explained as being deviations from an idealised development of high country yellow-brown earth (Taylor & Pohlen, 1962) from "greywacke" detritus (e.g., Table 2B), leached and podzolized under different regimes of moisture (precipitation, drainage, and evapotranspiration) and vegetation (tussock grassland, beech and podocarp forest).

Fig. 2.3 shows the distribution of soil types in montane Canterbury.

2.2 CLIMATE

2.2.1 Present Climate

Kidson (1950) and Garnier (1958) have presented comprehensive studies of the weather and climate of New Zealand. Aspects of the mountain weather and climate are provided by various writers (e.g., Watts, 1950; De Lisle, 1966, 1969; Coulter, 1967; Cherry, 1970; Morris, 1965; Morris & O'Loughlin, 1965; Greenland, 1977). De Lisle (1969) and Greenland (1977) have respectively reviewed the weather and climate of Canterbury and Cass.

New Zealand lies in a mid-latitude position in the Southern Pacific Ocean, in a position south of the high pressure zone of the sub-tropics and on the northern edge of the main belt of westerly winds. The domination of

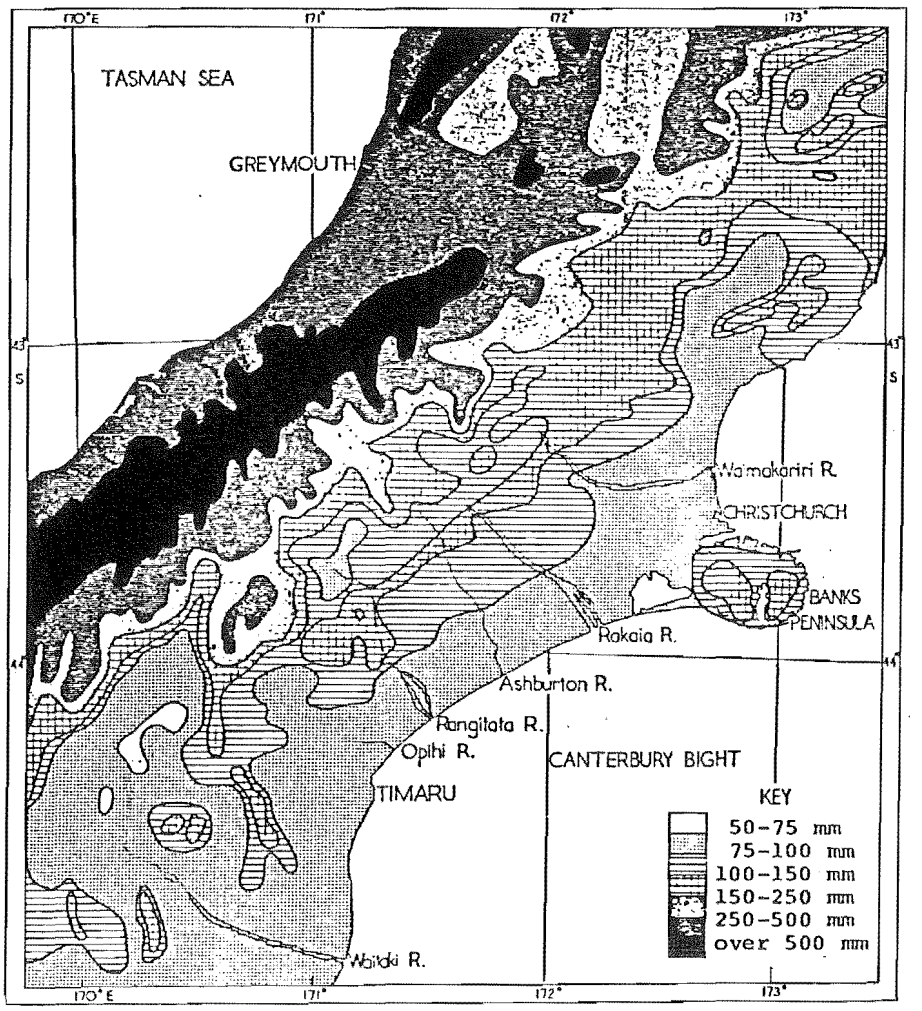
New Zealand weather by a regular procession (weekly period (De Lisle, 1969)), of anticyclones and troughs of low pressure moving eastward onto the country from the Tasman Sea, is a result of the intermediate position of New Zealand between these global circulation belts.

The Southern Alps of the South Island lie directly across the easterly progression of these weather systems. Their modification of these systems determine South Island weather. Orographic uplift of the westerly airstream results in high precipitation on the western slopes, and a strong föhn effect and rain shadow on the eastern side (Figs. 2.4, 2.5), producing the hot dry nor'wester - the characteristic wind of Canterbury. The less frequent southerlies, deriving from the troughs of low pressure in between the anticyclones, result in either cold fine weather in the Canterbury mountains or high winds with rain or snowfalls on the eastern peaks.

Climate records for the mountain areas are sparse and are generally limited to precipitation. Rainfall records are available for Lake Sumner and Lake Heron basins, and for Mt. Somers (Table 2C), and the eastern end of the transect in Fig. 2.5 crosses the Rakaia River in the vicinity of Prospect Hill.

More records are only available from the Cass area which has to be taken as being representative of other Canterbury intermontane basins including the Lake Heron and Lake Sumner study areas. At Cass, air temperatures are greatest in mid-summer (c. 15^{o}C monthly mean), and least in winter (c. 1.5^{o}C monthly mean) when frosts are

Figure 2.4. Distribution of mean annual rainfall (1921-1950) central South Island (after De Lisle, 1969).



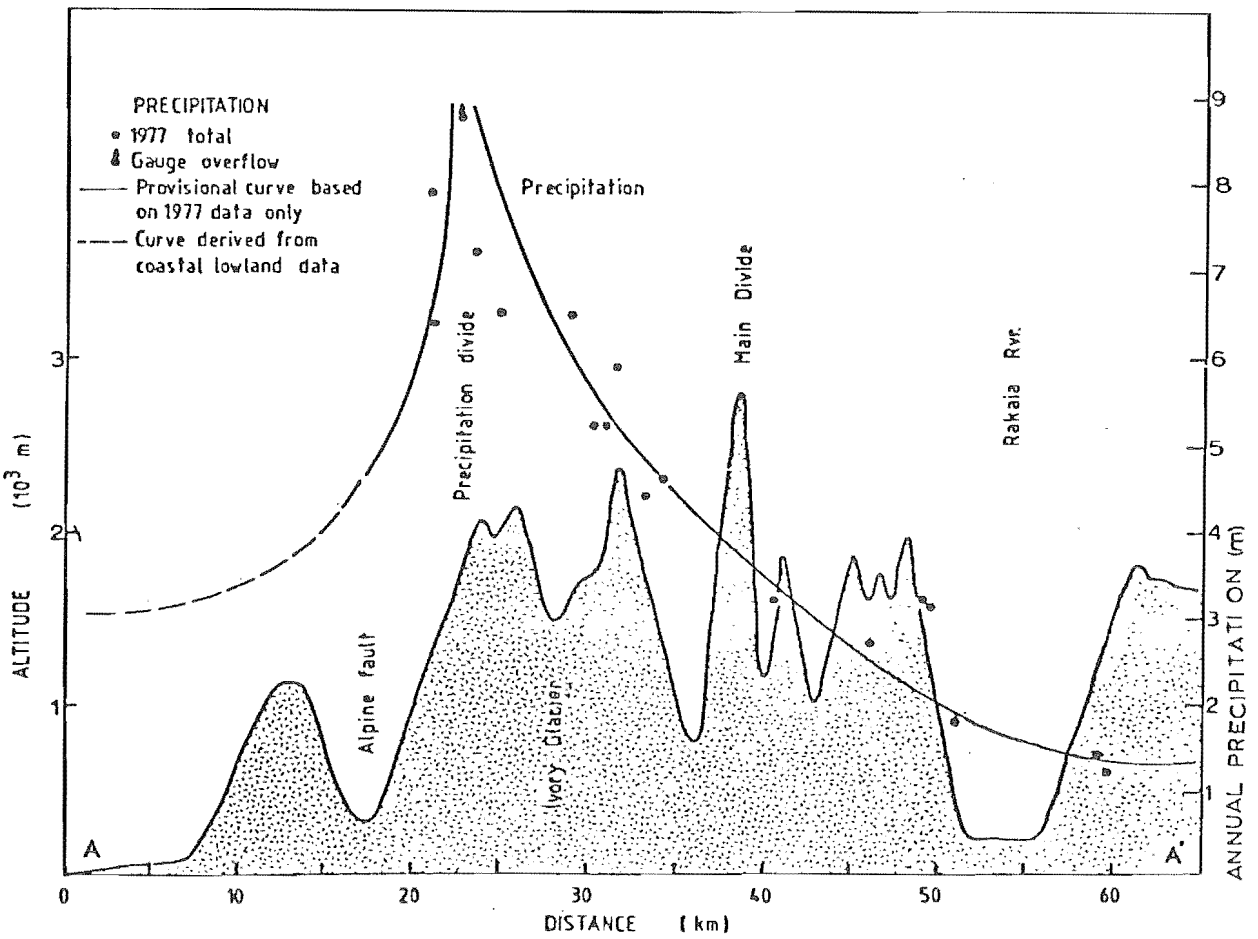


Figure 2.5. Topographic profile across the Southern Alps near Whitcombe Pass showing the gradient of total annual precipitation (from Chinn & Whitehouse, 1979).

Table 2C. Rainfall normals 1941-70 (mm) for the study areas and Cass. (abstracted from "Rainfall Normals for New Zealand 1941 to 1970". N.Z. Meteorological Service Misc. Pub. 145 & Supplement No. 1).

	Upper Rakaia district			Mt. Somers district				Cass distr.	Lake Sumner distr.
	Erewhon. 610 m H30581	Double Hill. 762 m H31321	Glenthorne. 610 m H31141	Mt. Possession. 610 m H31621	Woolshed Ck. 762 m H31631	Staveley. 381 m H31642	Taylors Strm. 732 m H31541	Cass. 610 m H31072	Lakes Station. 604 m H22721
Jan	152	99	107	84	-	119	-	94	90
Feb	137	107	109	76	-	109	-	97	100
Mar	140	94	107	76	-	109	-	96	100
Apr	140	122	130	76	-	107	-	107	110
May	130	127	145	71	-	97	-	114	120
Jun	84	109	119	48	-	64	-	97	90
Jul	114	122	132	64	-	84	-	99	120
Aug	124	135	132	71	-	91	-	104	120
Sep	119	132	145	66	-	86	-	119	90
Oct	140	135	142	76	-	104	-	122	110
Nov	152	132	147	86	-	117	-	130	100
Dec	170	119	127	94	-	135	-	107	120
Year	1602	1433	1542	888	1193	1222	1601	1276	1270

frequent (Table 2D). The most sunshine occurs in autumn (February-May) and wind velocities have an annual average value of 4.9 m/sec (C. J. Burrows, pers.comm.). Maximum gust velocities may be as high as 140 - 150 km/hr in places. Winds from the north-westerly quarter are most frequent,occurring 51% of the time (Table 2E). Local topography will alter these proportions depending on the site. In calm weather, katabatic cold air drainage at nights from the surrounding slopes results in temperature inversions being a frequent phenomenon. These occur all year round (up to 57% of the days in a year (Greenland, 1977)) and in winter are responsible for hard frosts. Annual average precipitation at Cass since 1918 has been 1 300 mm (surrounding mountains - 1 800 mm) and distributed fairly evenly throughout the year. Variability at 14.91% (Seelye, 1941) is relatively high, reflecting the location of Cass within a steep annual rainfall gradient: Arthurs Pass, some 20 km to the north-west has more than three times as much precipitation.

There are few records of precipitation in the form of snow. Very heavy snowfalls occur in some years (Burrows, 1976), but snow usually occurs only for a day or so on the floor of the Cass basin (Soons & Rayner, 1968). Snow is more frequent and of longer duration in the Lake Heron basin and less frequent in the Lake Sumner basin. Winter snowline in Canterbury may be as low as 915 m but permanent snowline is at about 2150 m.

Mt. Somers, on the eastern edge of the mountains overlooking the plains, lies in the foothills belt of

Table 2D. Mean air temperatures in °C from localities in the Cass district (from Greenland, 1977).

Station	Chilton Valley	Field Station	Craigieburn (Forest)
Altitude (m)	780	566	808
Approx. distance from Chilton Valley (km)	-	1	13
Years of Record	1964-68	1961-1964	1961-63
January	14.3	14.6	14.5
February	16.0	15.7	14.5
March	12.5	13.2	11.2
April	10.5	8.8	8.8
May	5.5	5.8	5.6
June	2.5	2.7	1.7
July	1.7	1.6	1.1
August	4.0	3.7	2.2
September	6.5	5.7	5.0
October	8.0	9.8	9.4
November	8.2	11.5	9.4
December	13.5	15.5	13.9
Year	8.6	9.0	8.3

Table 2E. Wind directions at Cass; morning observations (from Greenland, 1977).

N - NW - W	-	51%
S - SW	-	13%
SE - E - NE	-	16%
Calm	-	20%

of increased rainfall (see Fig. 2.4) that results from southerly and easterly winds, an effect which does not penetrate the mountains beyond the foothills.

2.2.2 Past Climate

The late Quaternary of New Zealand has been characterized by major fluctuations in climate. Evidence for these changes is largely derived from the lithology, fossil content, and physiography of the Hawera Series (Table 2F). Four glacials and four interglacials (including the Aranuian) are recognized. Evidence in Canterbury and Westland of several ice advances show that large fluctuations of climate occurred during the Otiran and to a lesser degree throughout the Aranuian (Table 2G). Evidence from other sources is summarized in Fig. 2.6.

The magnitude of the fluctuations in Otiran time was sufficient to cause heavy glaciation of the Southern Alps in Canterbury and Westland during the period of maximum cold (c. 20 000 yr B.P.). Fig. 2.7 shows the approximate extent of ice at the Otira glacial maximum and also the approximate shoreline position extended by glacio-eustatic lowering of sealevel. Estimates of the temperature of cold phases within the Otiran depend on snow-line depression information and range from 3^{o} to 6^{o}C below present mean annual temperatures (Willett, 1950; Porter, 1975).

A large scale retreat of ice and expansion of vegetation recorded a general warming of unknown magnitude and seasonal distribution starting about 14 000 years ago at the beginning of Aranuian time. Climate was mild enough to allow

Table 2F. Subdivision of the New Zealand Quaternary (from Mansergh, 1973a).

Subdivision of the New Zealand Quaternary

Series	Stage		Estimated Time (approx)		Basis of Subdivision
Hawera	Aranuian	(Interglacial)	0.014 m.y.	"UPPER QUATERNARY"	Climate Fluctuation
	Otiran	(Glacial)	0.07 m.y.		
	Oturian	(Interglacial)	0.13 m.y.		
	Waimean	(Glacial)			
	Terangian	(Interglacial)	0.25 m.y.		
	Waimaungan	(Glacial)			
	Waiwheran	(Interglacial)			
	Porikan	(Glacial) [1]			
			0.5 m.y.		
Upper Wanganui	Putikian[2]	Castlecliffian (s.l.)		"LOWER QUATERNARY"	
	Okehuan				
	Marahauan[2]	Nukumaruan (s.l.)			
	Hautawan[3]				
			1.8 m.y.		Biostratigraphy
Lower Wanganui	Mangapanian	Waitotaran (s.l.)		PLIOCENE	
	Waipipian				
	Opoitian				

1 The Porikan may be within the time range of the Castlecliffian; if so, it is incorrectly assigned to the Hawera series.

2 See Fleming (1953). Castlecliffian, Nukumaruan and Waitotaran have been used in a restricted sense by Fleming (1962) and Vella (1963) in place of Putikian, Marahauan and Mangapanian as in this volume.

3 The Hautawan is essentially dependent on northward migration of a cool-water marine fauna and is not clearly separable from the Marahauan by evolutionary marine biostratigraphy.

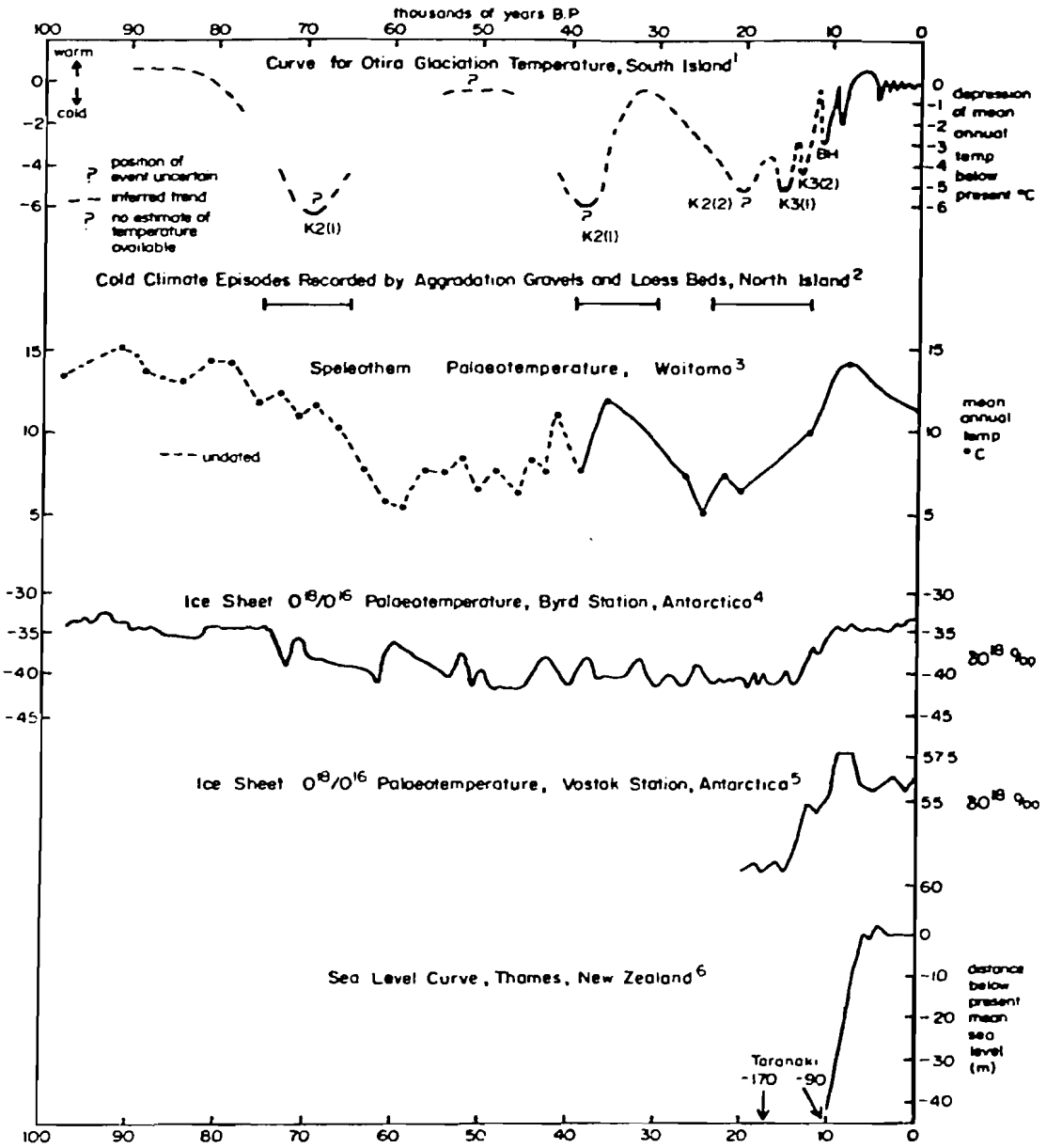
Table 2G. Tentative correlations of Otiran and Aranuian glacial events.*
(All dates in yr B.P. unless specified otherwise).

* The valley glaciers of the Southern Alps have complex and differing histories of advance and retreat. Correlation of these events is in a dynamic state. Intervalley discrepancies in correlation exist on both sides of the alps and east-west transalpine correlations, particularly of some Otiran glacial events, is not yet firmly established. (See Burrows & Mansergh (1973) pp.29,30; Soons & Burrows (1978); Burrows (1978) pp.84,85.)

	WESTLAND[1]	CANTERBURY				
		Waimakariri Valley[2]	Mt. Cook/ Tasman Valley[3]	Ben Ohau Range[4]	Rakaia Valley[5]	Cameron Valley/ Ashburton Valley[6]
ARANUIAN	1930 A.D. 1600-1850 A.D. (maximum) c. 400		younger	c. 100 Dun Fiunary c. 400	1930 A.D. Whitcombe c. 400	1930 A.D. Arrowsmith 1 413±50 A.D. (c. 550)
	1 095 c. 1 450 Horace Walker* 1 510		"Mount Cook"			
	2 380±75 c. 2 500 Horace Walker*, La Perouse* 2 570		older	Whale Stream 1 800 Jacks Stream 2 500	?Lyell	Marquee 2
	c. 4 500 Franz Josef*, La Perouse*, Horace Walker*, Fettes*			Ferintosh	Meins Knob c. 4 500	Marquee 1
			"Sebastopol"			? Lochaber
	c. 11 000 Franz Josef* (Waiho Loop)	McGraths Creek	Birch Hill	Birch Hill	10 000 Lake Stream c. 11 000 11 900	Wildman 1 & 2
	MAJOR RETREAT OF GLACIERS c. 14 000 - 13 000					
OTIRAN	Kumara 3_2	Poulter 2	Tekapo		Acheron 3	Lake Heron (pre. 11 900)
			Mt. John 2		Acheron 2	
	Kumara 3_1	Poulter 1	Mt. John 1		Acheron 1	
	Kumara 2_2	Blackwater 3 (complex advances)	Balmoral 2		Bayfield 3	Johnstone Stream
	Kumara 2_1	Blackwater 1,2	Balmoral 1		Bayfield 1,2	Emily
	Kumara 1	Otarama	? Wolds		Tui Creek 1,2,3	

* Glacier names

1. Grant-Taylor & Rafter, 1962; Suggate, 1965; Suggate & Moar, 1970; Wardle, 1973; Wardle, 1978
2. Chinn, 1976; Gage, 1958
3. Burrows, 1973; Burrows, 1980; Burrows & Mansergh, 1973 p.29; McGregor, 1967; Speight, 1963
4. McGregor, 1967; P. Birkeland pers.comm 1978, in Burrows, 1980
5. Burrows & Russell, 1975; Soons, 1963; Soons & Gullentops, 1973
6. Burrows, 1975; H.W. Keene, pers.comm.1977



1 Suggate (1965), Suggate & Moar (1970), Mansergh (1973b), Moar & Suggate (1973), Fleming (1972), Grant-Taylor (1964), Porter (1975); 2 Milne (1973); 3 Hendy & Wilson (1968); 4 Johnsen, Dansgaard, Clausen & Langway (1972); 5 Barkov, Godiyenko, Korotkevich & Kotlyakov (1975); 6 Schofield (1963).

Figure 2.6. Climatic variation during the Otira Glaciation (from Burrows, 1978).

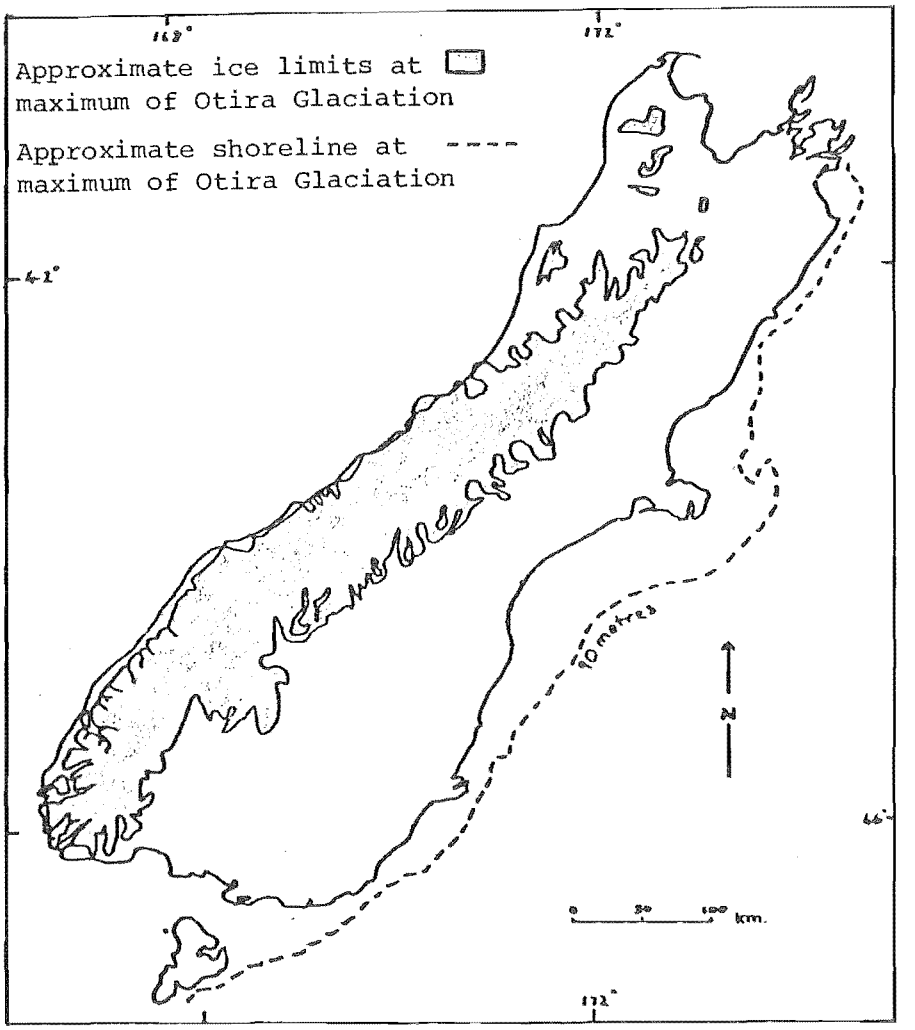


Figure 2.7 The approximate ice limits and shoreline (90 metres isobath) at the Otira glacial maximum (redrawn from Moar 1973b).

development of forest in the mountains later at about 10 000 yr B.P. There is little conclusive proof of a major change in post-glacial climate since then. Subsequent fluctuations in climate recorded mainly by glacial advances have been minor and have been of diminishing magnitude. Climate variations in the last 1 000 years in the South Island probably involved temperature changes of not much more than ± 0.5°C (Burrows & Greenland, 1979). In Canterbury these variations are only evident from minor glacial advances (e.g., McGregor, 1967; Burrows, 1973; Burrows & Russell, 1975; Burrows & Maunder, 1975). They are not recognized from the structure of Canterbury forests and are of too small a magnitude to be recorded by pollen diagrams.

2.3 VEGETATION

2.3.1 Preface

Godley (1975) provides a good general account of the vegetation of New Zealand and Holloway (1954) covers the forests of the South Island. Fig. 2.8 shows the main forest types and their distribution in the South Island. The most notable features are the absence of beech forest from the central South Island ranges and the extensive podocarp forests of central Westland compared with the very limited forests across the Main Divide in inland Canterbury.

The vegetation of the central South Island is covered in more detail by Wardle (1960) and Chavasse (1962) for Westland and by various authors in Knox (1969) for Canterbury. The broad altitudinal distribution of vegetation types

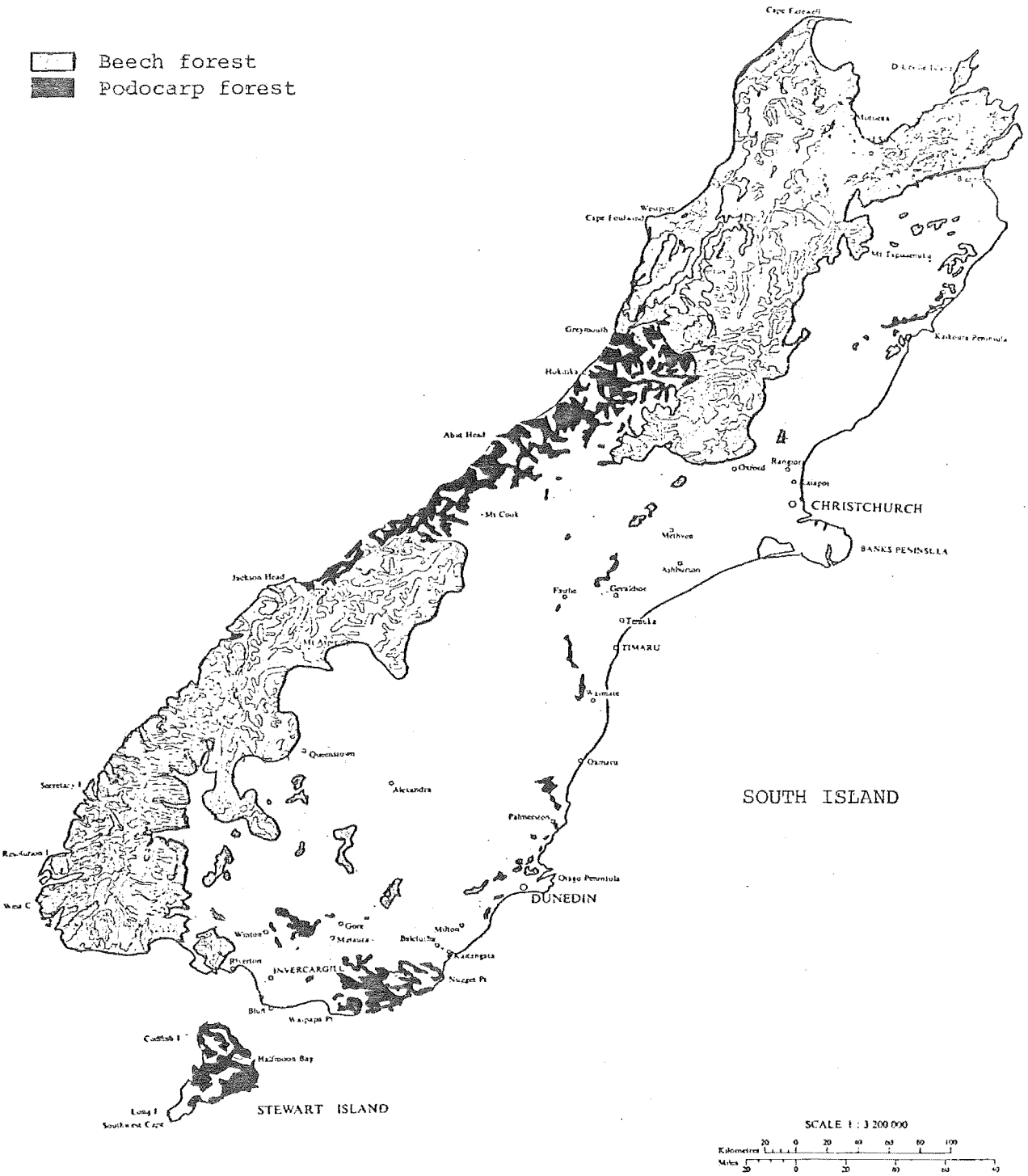


Figure 2.8 Distribution of indigenous forest, South Island and Stewart Island (modified from "Contemporary Forest Cover" map p.107, Wards,1976).

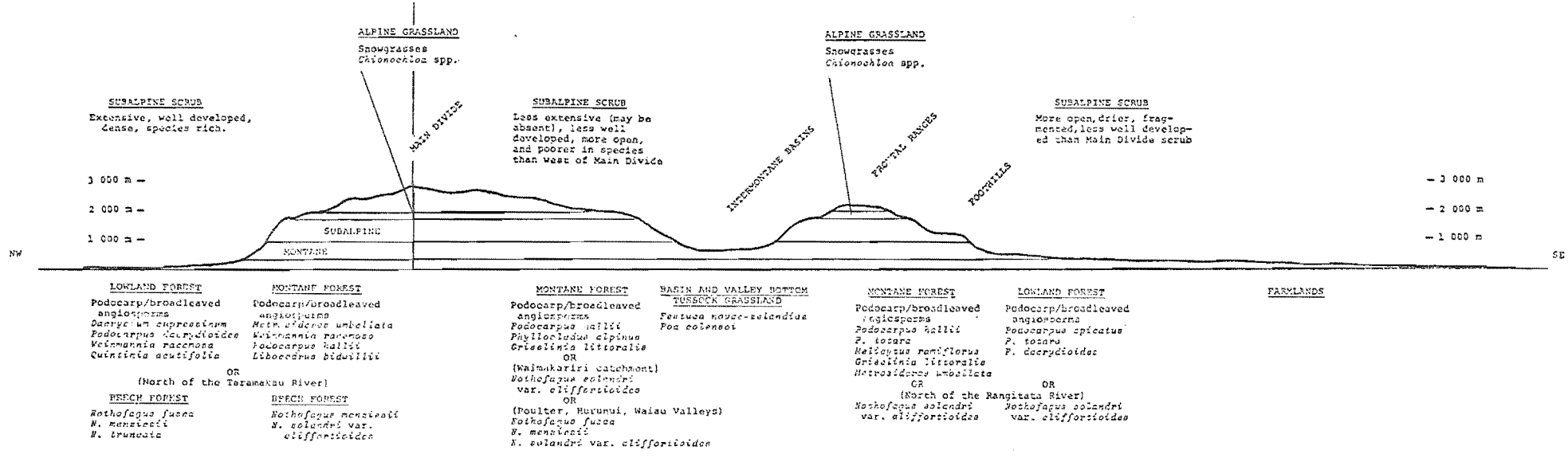


Figure 2.9 Altitudinal distribution of vegetation east and west of the Main Divide, central South Island.

across central South Island is outlined in Fig. 2.9. An altitudinal zonation of vegetation proposed by Burrows (1967), (Fig. 2.10) for mid-Canterbury serves as a framework within which to briefly describe the vegetation of montane Canterbury.

2.3.2 Forest

The forests of Canterbury (Fig. 2.11) are largely restricted to the mountains and foothills and are predominantly of mountain beech (*Nothofagus solandri* var. *cliffortiodes*). A few scattered remnants of a former *Podocarpus spicatus*, *P. totara*, *P. dacrydioides* podocarp forest occurs throughout lowland Canterbury and on Banks Peninsula. Podocarp forest in the mountains is restricted to the headwaters of the Wilberforce, Mathias, Rakaia, Lawrence, Clyde and Havelock rivers, and also occurs at Mt. Peel and the Hunters Hills in South Canterbury. The forest is patchy and is a species poor upland variant of the lowland forest type. *Podocarpus hallii* and *Griselinia littoralis* are the dominant canopy elements, and a varied understorey of evergreen shrubs and lianes is usually present. *Libocedrus* and *Metrosideros* may be occasionally present but kamahi (*Weinmannia racemosa*) probably the most common tree species in New Zealand forests, is rare. The forests may grade into, or form mosaics with, tall *Phyllocladus alpinus* stands.

These upland Canterbury podocarp forests are fragmented and are of varied composition compared with the extensive *Nothofagus* beech forests.

The beech forests are very simple in composition, with

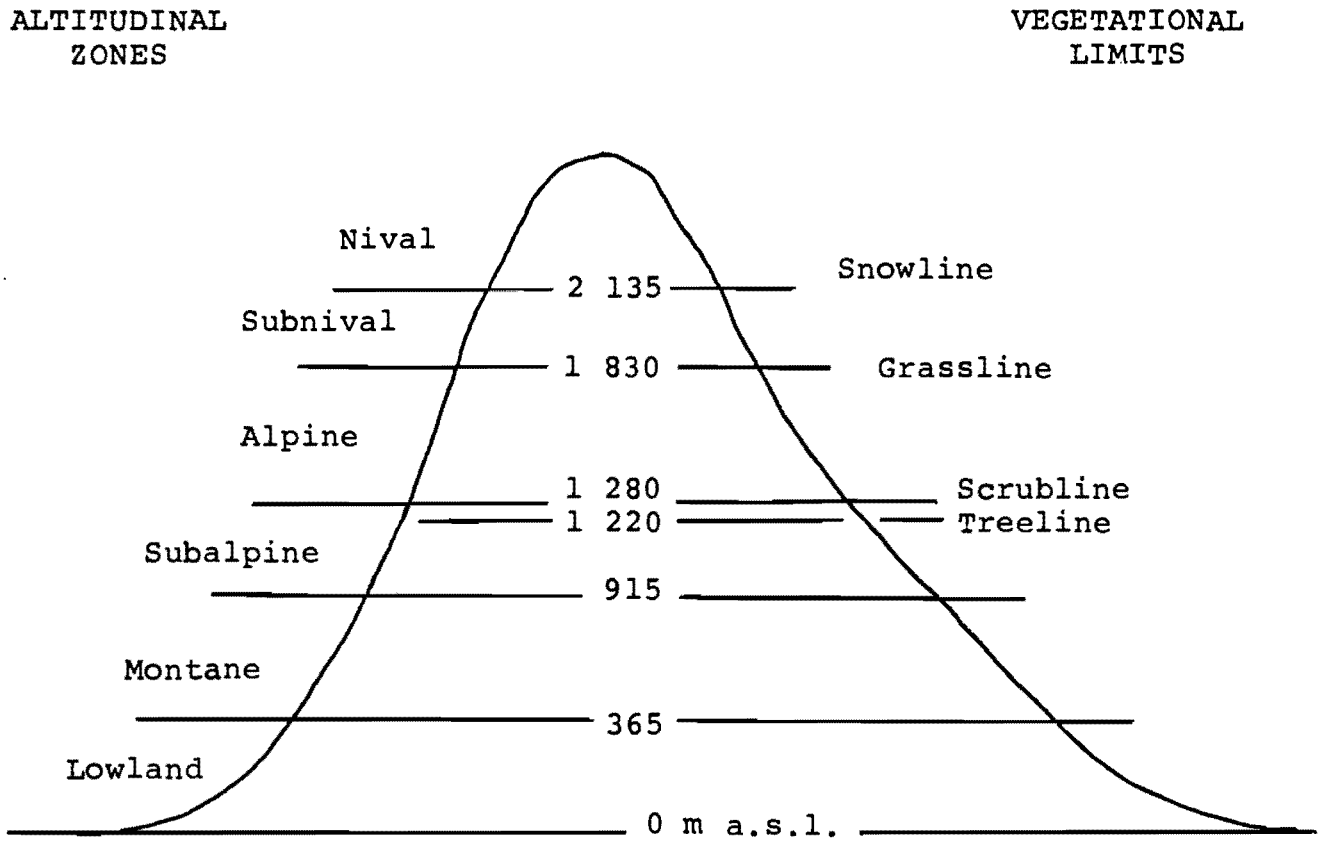
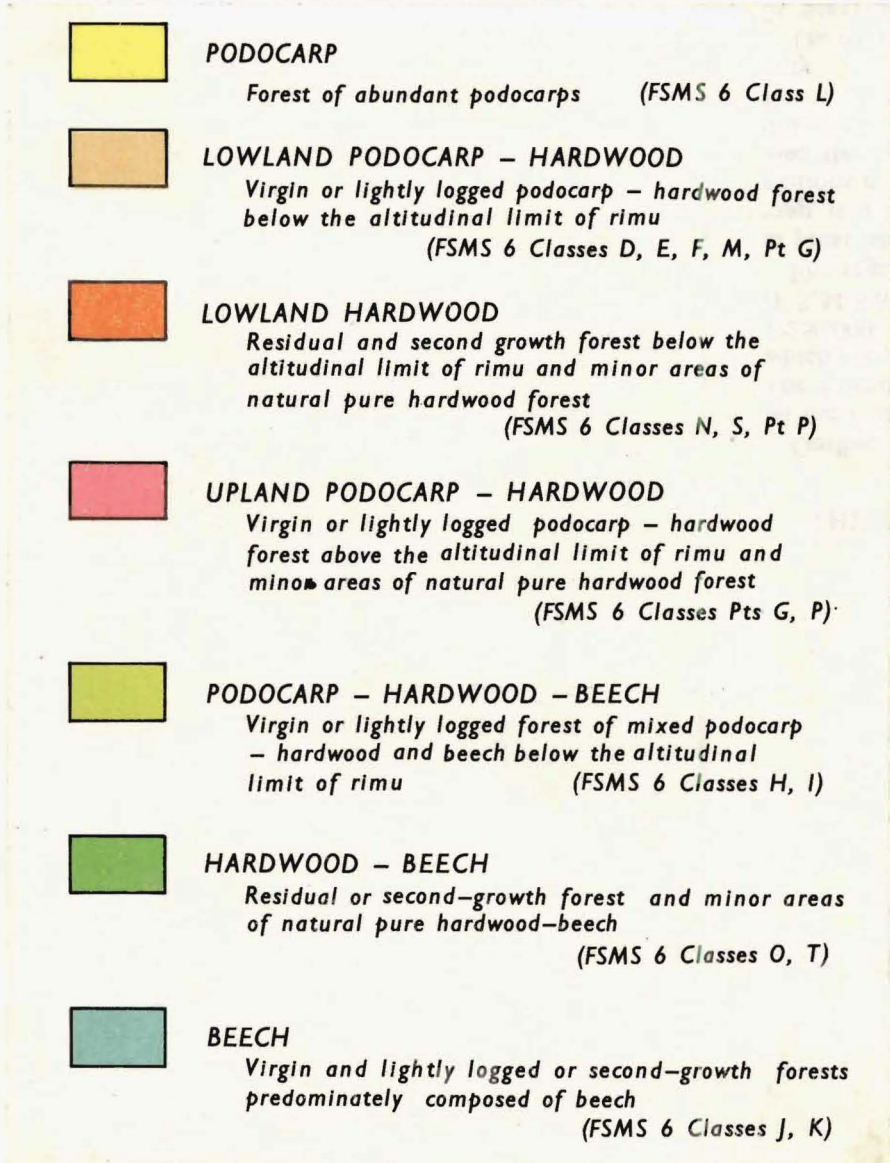


Figure 2.10 Altitudinal limits of vegetation in mid-Canterbury 43°S. (after Burrows, 1967). Zone limits are irregular and vary from the general limits given. In the drier eastern ranges snowline is higher by up to 300 m and grassline lower by 150-300 m. Zone limits are lower in the central mountains and near glaciers and are altered where there has been a history of fire.

Figure 2.11 Distribution of indigenous forest in central South Island including Canterbury, (from New Zealand Indigenous Forests, South Island. N.Z. Forest Service Mapping series No. 15, 1st Edition, 1974).



◁ Isolated stands of silver beech occurring within the "beech gap" in Canterbury.


PROJECT
C. Foulwind
Buller R
Westport
Pt. Elizabeth
GREYMOUTH
Grey R
Tiramakau R
Hokitika
Mikonui R
Wanganui River
Abut Head
Whataroa River
Waitaha R
Waiho River
Omoeroa R
Waikukupa R
Gillespie Pt
Cook R
Okuru
Okuru River
Karangarua River
Makawhio Pt
Bruce Bay
Heretaniwha Pt
Tititira Head
Paringa
Lake Paringa
Lake Wanaka
Lake Hawea
Lake Dunstan
Lake Roxburgh
Lake Onslow
Lake Coleridge
Lake Ellesmere
Lake Forsyth
Lake Ellesmere
Lake Wairewa
Lake Forsyth
Lake Wainono
Lake Waihola
Lake Waipori
Lake Mahinerangi
Lake Tuakitoto
Lake Hayes
Lake Wakatipu
Lake Wanaka
Lake Hawea
Lake Dunstan
Lake Roxburgh
Lake Onslow
Lake Coleridge
Lake Ellesmere
Lake Forsyth
Lake Wainono
Lake Waihola
Lake Waipori
Lake Mahinerangi
Lake Tuakitoto
Lake Hayes
Lake Wakatipu
WESTERN
EASTERN
CANTERBURY BIGHT
BANKS PENINSULA
ARTHURS PASS NATIONAL PARK
LAKE SUMNER STATE FOREST PARK
CRAIGIEBURN STATE FOREST PARK
WESTLAND MOUNT COOK NATIONAL PARK
NATIONAL PARK
CHRISTCHURCH
TIMARU
ASHBURTON
Motunau I
Kaikoura
Kaikoura Peninsula
Kaikoura Head
Hurunui R
Waiau R
Waiau River
Waiau Toa
Waiau Pa
Waiau Ck
Waiau Ck
Waiau Ck

mountain beech being the main species and indeed the sole species in the forests of most of the Waimakariri catchment and in the Harper-Avoca catchments in the Rakaia. The beech forest understorey is typically sparse and is floristically poor compared with that of podocarp forests. It may be limited to a ground cover of divaricating shrubs (e.g., *Coprosma* spp) in wetter areas; the ground fern *Polystichum vestitum* in drier areas; or may be entirely depleted by the introduced red deer (*Cervus elaphus*) and possum (*Trichosurus vulpecula*). Red beech (*Nothofagus fusca*) and silver beech (*Nothofagus menziesii*) are both abundant in the Waiau and Hurunui forests and in the upper Poulter River and the Otehake tributary of the Taramakau across the Main Divide. Red beech is also present in some of the eastern tributaries of the Waimakariri River, and a stand at Mt. Oxford forms the southern limit in Canterbury. Isolated small stands of silver beech however, occur southward throughout an area otherwise without beech forest (the "beech gap") in Canterbury. Fragments of silver beech forest occur at the Hawdon River in the Waimakariri watershed, Mt. Somers, Lake Stream, the South Opuha River near Burkes Pass, Coal Creek in the eastern Hunters Hills, and at Governors Bush near Mt. Cook. Hard beech (*Nothofagus truncata*) has not been found in Canterbury and the presence of true black beech (*N. solandri* var. *solandri*) is uncertain. Mountain totara (*Podocarpus hallii*) occurs scattered throughout most beech forest, being usually more common in the drier eastern ranges. Where beech forest adjoins podocarp forest mixed types of forest occur.

2.3.3 Subalpine scrub

A belt of subalpine scrub commonly occurs between the montane forests of the lower slopes and the alpine grasslands and subnival herbfields above. This belt varies widely in composition and extent and in some dry areas may not be present above beech forest at all. It is best developed in high rainfall areas such as the Westland mountains and is less extensive on the drier eastern flanks of the Main Divide. In Canterbury the most extensive areas of subalpine scrub are present within the "beech gap" in the upper Rakaia and Rangitata catchments. A variety of habitats influenced by dryness, unstable slopes, and often a long fire history, results in a complex of communities in which shrub species of *Dracophyllum*, *Coprosma*, *Olearia*, *Senecio*, and *Hebe*, are common together with *Phyllocladus alpinus* and *Podocarpus nivalis*. Wardle (1969a) provides more detail.

2.3.4 Alpine and subalpine grassland

Extensive alpine and subalpine tussock grasslands lie above the forest and subalpine scrub. Some five species of snowgrass (*Chionochloa*) are dominant and provide most of the cover. Herb fields and unstable fell fields occur within and above the alpine grasslands and include a wide variety of herbaceous, semi-woody and small woody species. Many species have wide ecological tolerances and are widespread throughout the Southern Alps. However Burrows (1965) has demonstrated the existence of distinct endemic distribution patterns. The alpine flora of

Canterbury is shown to be unspecialized and drawn from species common to the Alps as a whole, in contrast with the alpine floras of Nelson-Marlborough and Otago-Southland which display high degrees of endemism. Generalized distributions are given by Burrows (1969a). The patterns of the distributions match that for beech.

2.3.5 Post-glacial history - South Island

The present day distribution of vegetation in the South Island is largely the result of historical factors including glaciation, climate variation and fire (both natural and man-made). The "beech gap" in the central South Island mountains, and also the northern and southern ranges of endemism in the alpine flora, are attributed respectively by Wardle (1963), and Burrows (1965), to obliteration of vegetation in the severely glaciated central Southern Alps during the last (Otira) glaciation; a view first proposed by Cockayne (1926) and later by Willett (1950). The isolated *Nothofagus menziesii* stands within the "beech gap" in Canterbury (their origin long a source of conjecture) are now generally thought to be derived from relicts that have somehow survived the Otira Glaciation (e.g., Molloy & Cox, 1972). Differential adjustment to post-glacial conditions is still going on (Moar, 1971; Moar & Lintott, 1977), and the pattern has been further complicated by climatic oscillations and fire episodes (Molloy, 1969a).

Post-glacial development of the vegetation in the Southern Alps may be summarized in the five pollen zones of Moar (1971):

1. Grassland - Shrubland
2. Shrubland
3. *Podocarpus* forest (in north Westland, *Weinmannia* forest)
4. *Nothofagus* forest (in north Westland, *Dacrydium cupressinum* forest)
5. Deforestation - only recognised in Canterbury.

Table 2H provides more detail.

The timing of these changes in vegetation type is broadly known, but as yet, insufficient dates are available for the complexity of the progression to be revealed.

The end of the Otira glaciation has been taken as occurring 14 000 years ago (Suggate, 1965). It is likely that grassland and shrubland vegetation already existed in inland Canterbury at this time.

Forest (podocarp) expansion in the South Island probably occurred about 10 000 years ago but is not necessarily thought to have been a synchronous event (Moar, 1971).

The spread of beech forest in the South Island has been shown to be diachronous in Westland by Moar (1971). Radiocarbon dated pollen diagrams from several north Westland sites have shown that the spread of beech occurred at sequentially later times southward from Nelson over a period of more than 5 000 years. The spread of beech forest in eastern South Island has not been extensively or precisely dated and its metachroneity has not yet been established. Radiocarbon dates from the Cass district show that beech began to spread sometime between 5 000 and 8 000 years ago (Lintott & Burrows, 1973, Burrows unpub.).

Table 2H Patterns of post-glacial vegetation development west and east of the Main Divide, South Island (modified from Moar 1973b).

POLLEN ZONES	West			East			
	GILLESPIES BEACH ROAD ca. 70 m	BELL HILL ca. 160 m	CROOKED MARY CREEK ca. 420 m	CASS BASIN ca. 660 m	RUBICON CK. ca. 500 m	CASS ROAD ca. 130 m	TIMARU ca. 30 m
5				← Deforestation →			
4	*Dacrydium cupressinum*	*Dacrydium cupressinum* + *Nothofagus* / *Dacrydium cupressinum*	*Nothofagus*	*Nothofagus*	*Nothofagus/ Podocarpus*	*Nothofagus/ Podocarpus*	
3	*Weinmannia/ Dacrydium cupressinum*	*Weinmannia*	*Dacrydium cupressinum/ Podocarpus*	*Phyllocladus/ Podocarpus*	*Podocarpus*		*Podocarpus*
2	*Coprosma/ Myrsine*	*Coprosma/ Myrsine*	*Phyllocladus/ Dacrydium bidwillii*	*Phyllocladus* / *Dacrydium bidwillii*	*Phyllocladus*		*Plagianthus*
1		Gramineae		Gramineae	Gramineae		

Main Divide

In Canterbury the extensive destruction of forest by fire (almost certainly of Polynesian origin) is recorded by pollen diagrams and widespread forest charcoals throughout the mountains and plains. Radiocarbon dates from a number of sites concentrated in the Cass district place the occurrence of this event fairly reliably between 500 and 600 years ago (Molloy, 1977). Elsewhere in many parts of the eastern South Island there is a similar range of dates for Polynesian fires.

CHAPTER 3

METHODS

3.1 FIELD

Sampling was carried out using a Hiller corer with a 30 cm x 2 cm chamber. Specific sites for boring were chosen after probing to find the deepest part of each bog. Samples were extracted alternately from two holes about 30 cm apart in order to reduce down-hole contamination. After the sediment type had been noted, the chamber was sampled at 5 cm intervals with a spatula and the samples were stored in glass vials. The residue was then examined for macrofossils. A handful of moss formed the surface sample at all sites except Mt. Somers where the topmost 0.5 cm of tarn sediment was used.

Samples for radiocarbon dating of the main diagrams (Quagmire Tarn, Raupo Pond) were collected at the requisite depths after rough pollen profiles had been constructed. The great depth of sediment encountered at Raupo Pond permitted the dating of only the most recent major change in vegetation - the spread of beech. A Hiller corer of 50 cm x 10 cm chamber size was needed in order to obtain a large enough sample. The ^{14}C sample was taken from the centre of the chamber and pollen samples taken the length of the chamber were later analysed to provide a position check by fit on the pollen diagram.

3.2 LABORATORY

Samples were stored at 4°C. The standard potassium hydroxide, hydrofluoric acid, acetolysis, stain technique as outlined in Faegri & Iversen (1964) was used. Difficult samples required variations or repeats of this basic treatment and/or further oxidising or dispersive treatments, e.g., Faegri & Iversen (1964); Kummel & Raup (1965); Lennie (1968); McIntyre & Norris (1964). Samples were mounted in glycerine jelly on two slides. The initial identification of pollen and spore types was carried out with the help of Dr. N.T. Moar and the DSIR Botany Division pollen reference collection. The level of unknowns in any one sample was not allowed to exceed 2% and was for the most part far less than 1%. Residues obtained in the course of pollen extraction were examined for macrofossils.

Radiocarbon samples were checked for carbon content and air dried before being dated at the New Zealand Institute of Nuclear Sciences, Wellington. Samples were 'whole sediment' samples untreated in any way apart from drying.

An attempt to check for modern atmospheric pollen contamination in the laboratory was made. Vaseline-coated catch slides were exposed on the workbench and in the fume cupboard during the preparation of all samples. The slides were simply checked by immersing in stain, air drying and scanning. No significant contamination was found to be present.

Slides were traversed at half field diameter spacing at a routine magnification of 400x until a minimum count

of 200 pollen grains or spores of land plants was achieved. Many authors have used very different counting sums depending on the areas and purposes of study, e.g., Jorgensen (1963, 1965); Coetzee (1967); Dodson (1974). Much thought has also been given to the statistical errors in the production of a pollen diagram with the size of the counting sum receiving attention, e.g., Faegri & Iverson (1975). The generally accepted minimum counting sum of 200 pollen of land plants was chosen with one simple running check being made for each zone of each diagram. This consisted of increasing the counting sum in steps of 25 until fluctuations in the percentage frequencies of the important taxa smoothed out. In the early scrub-grassland zones the smoothing point tended to occur at values greater than 200 and counts of around 300 to 400 were used where pollen numbers permitted.

3.3 DIAGRAM CONSTRUCTION

The diagram used is the standard percentage representation format originally proposed by von Post (1916) and followed with minor variations by many workers throughout the world.

3.3.1 Analysing Interval

The interval between analyses was shortened until reasonably smooth curves were established in the pollen profiles of the main taxa. Assuming a constant rate of deposition (judged from the radiocarbon-dated sequences) this resulted in an analysing interval of about 500 years

for all diagrams except Mt. Somers where the interval may be about 1 000 years. Points of special interest in the pollen diagrams were analysed at closer intervals as desired.

3.3.2 Pollen Sum

As Faegri & Iversen (1975) have pointed out, the choice of taxa to be included in the pollen sum depends on the purpose of the investigation and on the nature of the vegetation involved. As the purpose of this study is to examine the Aranuian development of forest vegetation, the hydroseral changes are not examined in detail. Spores and pollen of aquatic plants are excluded from the pollen sum. Pollen and spores from the on-site bog plants are also excluded from the pollen sum. Care has been exercised in deciding whether the represented taxa are part of the on-site vegetation or not. The decision in marginal cases such as Cyperaceae is somewhat arbitrary. In general, the pollen type is excluded from the sum if macrofossils of the parent plants are abundant in that part of the profile,or if gross over-representation is present causing distortion of the pollen spectrum. The representation of insect-pollinated plants poses obvious problems. Pollen of entomophilous plants is included in the sum except where gross over-representation is considered to have occurred.

The problems surrounding the relationships of the counted pollen with the *in situ* pollen, the *in situ* pollen with the pollen rain, and the pollen rain with the parent vegetation are numerous and complex. The problems accompanying data representation are equally so. A pollen

diagram is an attempt to present the data in an easily assimilated form and is necessarily an imperfect record. A careful interpretation of a pollen diagram therefore demands a knowledge of the limitations inherent in its construction and an appreciation of the factors involved in pollen production, dispersal, preservation, and recovery. These problems of representation are well known and will be discussed only in relation to the interpretation of the data in this study.

The pollen sum for all the main diagrams except Springs Bog comprises the total pollen of land plants. In the Springs Bog diagram where interest lies in the composition of the beech forest, the pollen sum is total pollen of *Nothofagus*. Various pollen sums are used in special purpose supplementary diagrams.

3.3.3 Format

Layout is similar to other diagrams from the South Island to facilitate comparison. The taxa are broadly grouped into naturally occurring, present day, communities arranged so that the progression of change is clearly seen. A summary diagram is included wherever it is thought to be useful.

Individual pollen profiles are not continued towards a sample point where pollen of that type is not present. If at least one grain is recorded then the adjacent traces are brought to zero at that point.

'Trace' levels are frequencies less than 1% and are represented in the diagram by abbreviation or vertical dash.

'Trees' in the summary diagram includes *Nothofagus*, *Podocarpus*, *Dacrydium cupressinum* and *Phyllocladus* which is classed here as a tree although more usually regarded as a shrub (e.g., Moar, 1971). Where dominant today in the Rakaia headwaters *Phyllocladus alpinus* forms a low forest with a tight, even canopy 6 m or more high. However, naturally some pollen at least will have derived from shrub-sized plants.

3.3.4 Zonation

The diagrams are zoned according to the predominant pollen type in order to aid description and interpretation. Positioning of zone boundaries can be difficult where the ranges of successive dominant pollen types overlap. The convention observed in delineating zones is that a zone boundary is drawn at the foot of the rise to dominant values of that pollen type which characterizes the zone. The upper limit of a zone is therefore defined by the curve of the characteristic pollen type of the succeeding zone.

The pollen zones are based on the pollen data alone but are not in any sense formally defined and named biostratigraphic units (c.f. Geological Society of New Zealand Guide to Stratigraphic Nomenclature, 1967). The pollen zones in the local chronologies erected for each site are named for the site, so that their identity is retained when being discussed or correlated.

This general usage of zone conforms with the findings of the Royal Society of New Zealand Report on Stratigraphic Nomenclature in the New Zealand Quaternary (1977).

3.3.5 Conventions used

Pollen and spore typology. Palynomorphs may often only be identifiable to generic or family level. Some of these groupings represent a collection of species which includes a wide variety of form and/or habitat, e.g., Compositae, *Podocarpus*, *Coprosma*, *Nothofagus fusca* type. Other identifications may be more specific, e.g., *Podocarpus dacrydioides*. A knowledge of the local vegetation, and of species distribution patterns and habitats often permits a more specific identification of the plant likely to be represented, (e.g. *Phyllocladus* as almost certainly entirely *P. alpinus* pollen). Confirmation is often provided by macrofossil evidence. This becomes evident in the text.

'*Nothofagus fusca* type' includes the pollen of all *Nothofagus* species* except *N. menziesii*. Mountain beech, *Nothofagus solandri* var. *cliffortioides* is likely to have been the species represented in the Rakaia and Mt. Somers diagrams but *N. fusca* could also be represented in the Lake Sumner district sites.

'*Podocarpus*' includes the pollen of all *Podocarpus* species except *P. dacrydioides* which is easily distinguished by its three bladders. The forest species *P. totara*, *P. hallii*, *P. spicatus*, and *P. ferrugineus*, may be considered to be the main contributors. Pollen of these species were not able to be consistently distinguished, but subjective estimations of dominance (dominant/not dominant) could be made for *P. spicatus*, *P. ferrugineus*, and *P. totara/P. hallii*. In the Rakaia region *P. hallii*

* *N. fusca*, *N. truncata*, *N. solandri* var. *solandri*, and *N. solandri* var. *cliffortioides*.

is thought to have been the main species represented, although some pollen of the shrub *P. nivalis* is probably present, more particularly in the early scrub phases.

'*Dacrydium bidwillii* type' includes the pollen of *Dacrydium bidwillii*, *D. biforme* and *D. laxifolium*. The main contributor is probably *D. bidwillii* although *D. biforme* may assume importance at high altitude sites. *D. laxifolium* is uncommon in the study areas.

'Monolete' and 'Trilete' respectively include all monolete and trilete fern spores.

Sediment types. All attributes were described in the field from the fresh cores. In description, each adjective qualifies the following one with the last adjective describing the predominant attribute. Thus grey brown silty sand is vastly different from brown grey sandy silt.

'Micromud' - fine organic mud in which no organic or mineral component can be distinguished by sight or feel.

'Macromud' - organic mud in which organic structures are evident by feel and to the unaided eye.

Location in relation to site.

'On-site' - refers to the nearest non-aquatic vegetation to the coring site. At the forested site this would include any immediate marginal shrub zone and the first few metres of surrounding forest.

'Local' - within about 1 to 2 km of the site.

'Extra-local' - within the valley in which the site is situated.

'Regional' - central South Island including Westland, mid-Canterbury and North Canterbury.

Radiocarbon dates. All ^{14}C dates are given in years before present (B.P.) which is 1950 by convention. The dates are based on the Libby ^{14}C half life of 5 568 years and are uncorrected for secular effects.

Current work in New Zealand is showing that ^{14}C dates from untreated charcoal, wood, and peat material are unreliable (e.g., Goh & Molloy, 1972, 1978, 1979; Molloy 1977; Goh *et al.*, 1978). Major factors involved are: firstly, sample contamination by younger carbon in the form of translocated soluble soil organic compounds causing younger-than-true ^{14}C dates; and secondly, the wide age-range of wood that is available for burning in a forest fire (trees of 1 000 year lifespan), which leads to older-than-true dates. Pretreatment techniques to remove younger carbon results in improved reliability.

The variability of these errors means that systematic correction is unlikely and it is difficult at this early stage to be able to estimate the reliability of the radiocarbon dates in this study which were obtained several years ago from untreated material.

Ranges of error for dates of Polynesian fires are likely to be of the order of 200 years (e.g., Molloy, 1977 p161) and are probably caused mostly by the age-range of the wood burnt. In older materials contamination by younger carbon becomes more important, and true ages could be 500 to 1 000 years older (e.g., *Phyllocladus/Podocarpus* charcoal untreated - 6 720±100 yr B.P., pretreated - 7 450±70 yr B.P. (Molloy, 1977); peat untreated - 9 610±100 yr B.P., pretreated - 10 050±100 yr B.P. (Goh *et al.*, 1978)).

Symbols and abbreviations. As detailed in Table 3A.

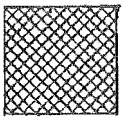
Table 3A Abbreviations and symbols associated with pollen diagrams.

PLANTS

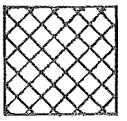
A	*Ascarina*
Ac	*Acaena*
Al	Araliaceae
Ar	*Aristotelia*
Az	*Azolla*
Ca	*Casuarina*
Ch	Chenopodiaceae
Co	*Coriaria*
Cy	Caryophyllaceae
D	*Dacrydium bidwillii* type
Dr	*Dracophyllum*
E	Elaeocarpaceae
Eh	*Elaeocarpus hookerianus*
Ep	*Epilobium*
G	*Griselinia*
Ga	*Galium*
Ge	*Gentiana*
Gr	*Geranium*
Gu	*Gunnera*
H	*Hoheria*
Ha	*Haloragis*
Hm	Hymenophyllaceae
Hy	*Hydrocotyle*
L	*Leptospermum*
Li	*Libocedrus*
Ly	*Lycopodium*
M	*Metrosideros*
Mo	*Myriophyllum*
Mr	Myrtaceae
Mu	*Muehlenbeckia*
My	*Myrsine*
Nf	*Nothofagus fusca*
Nm	*Nothofagus menziesii*
Ns	*Nothofagus solandri* var. *cliffortioides*
O	Onagraceae
P	*Plagianthus*
Pa	Papilionaceae
Pd	*Podocarpus dacrydioides*
Ph	*Podocarpus hallii*
Po	*Plantago*
Pr	*Phormium*
Ps	*Phymatodes*
Pt	*Potamogeton*
Pw	*Pseudowintera*
Px	*Pseudopanax*
Py	*Phyllocladus*
R	Rosaceae
Ra	Ranunculaceae
T	*Tupeia*
Te	Tetrad
Th	Thymelaeaceae
U	Umbelliferae
W	*Weinmannia*

Table 3A (cont.)

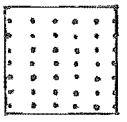
SEDIMENTS



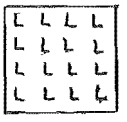
micromud



macromud

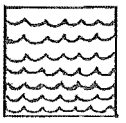


silt and sand

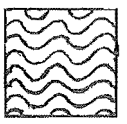


clay

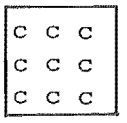
rootlets



water

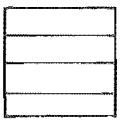


Sphagnum peat



charcoal

sedge leaves or peat



fibrous, or fibrous roots

fibrous sedge peat

rock

COLOURS

Y	yellow
B	brown
G	grey
U	blue
R	red
O	orange
X	black
L	light
D	dark

SITES

QT	Quagmire Tarn
WT	Windy Tarn
MS	Mt. Somers
BS	Blondin Stream
RP	Raupo Pond
SB	Springs Bog

A.P.	Arboreal pollen
N.A.P.	Non arboreal pollen
L.D.D.	Long distance dispersal

CHAPTER 4

SITES

4.1 CHOICE OF STUDY SITES

Prospect Hill in the Rakaia valley fulfilled several requirements. It was close to contacts of beech forest with montane podocarp forest; it was near to one of the isolated occurrences of silver beech; and was in a truly montane situation close to the Main Divide unlike other Canterbury sites. Good sampling sites were available on moraines whose stratigraphic relations were being worked out (Burrows & Russell, 1975) and the forests in the area showed evidence of considerable alteration by fire. Two sites were chosen, Quagmire Tarn and Windy Tarn.

A short *Nothofagus menziesii* pollen record at Prospect Hill failed to conclusively demonstrate that the anomalous distribution of this species in montane Canterbury could be due to local survival during the late Otira glacial. This led to a search for an eastern survival site in the frontal ranges. The nearest silver beech was present at Mt. Somers some 40 km distant. A high altitude site (Mt. Somers) and a low altitude site (Blondin Stream) were chosen to cover both hillslope and lowland habitats and also to permit an insight into the past relations of hillslope to upper plains forest.

Sites were located in the Lake Sumner district in order to investigate the Aranuian development of forest and the spread of beech in the montane forests north of

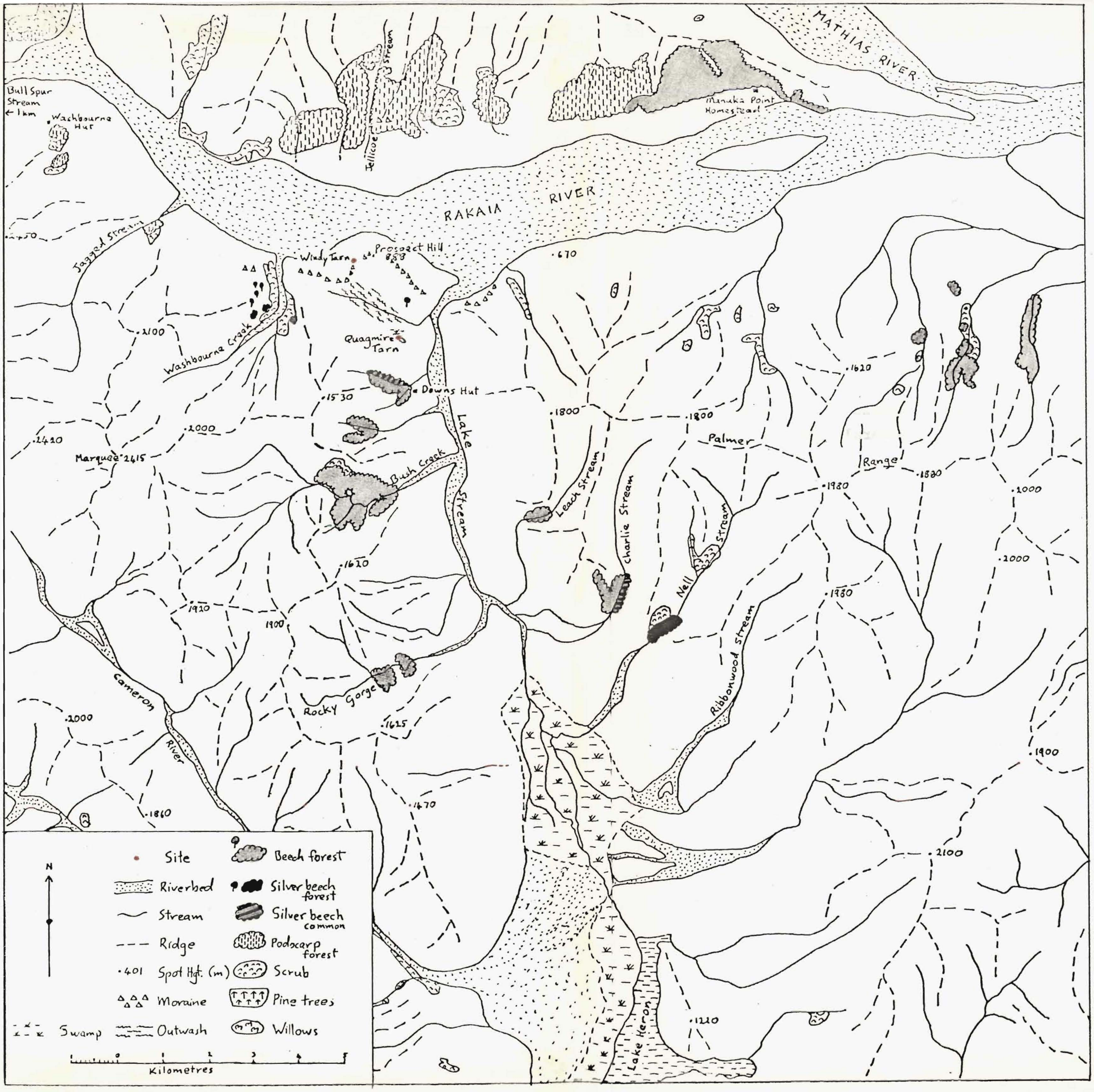
the Cass and Lake Heron districts; to examine the history of the important silver beech forest component there; and to determine the history of fire in the area. Sites were available within mapped moraines. The initial site (Springs Bog) to the west of Lake Sumner in the Hurunui Valley was shallow and proved to have too short a history. Raupo Pond in the Sisters Stream valley to the south of Lake Sumner and further away from the Main Divide than Springs Bog, proved to be a satisfactory site.

Each site is described in terms of location, site physiography, local and extra-local vegetation, and relation to the vegetation of neighbouring catchments.

4.2 RAKAIA SITES

Prospect Hill (Figs. 1.1, 4.1, 4.2) is situated in the upper Rakaia valley at the confluence of Lake Stream and the Rakaia River. It is a broad expanse of rolling downland consisting of bedrock covered by superficial glacial deposits, with a low summit (888 m) at the northern end which juts out into the Rakaia valley. Moraine of the Lake Heron advance of the Rakaia glacier, correlated with the Poulter advance of the Otira Glaciation in the Waimakariri valley (Soons, 1963; Burrows & Russell, 1975), completely covers Prospect Hill, while a moraine from a later advance of the Rakaia ice (Lake Stream advance) is plastered against the northern part not quite overtopping the peak.

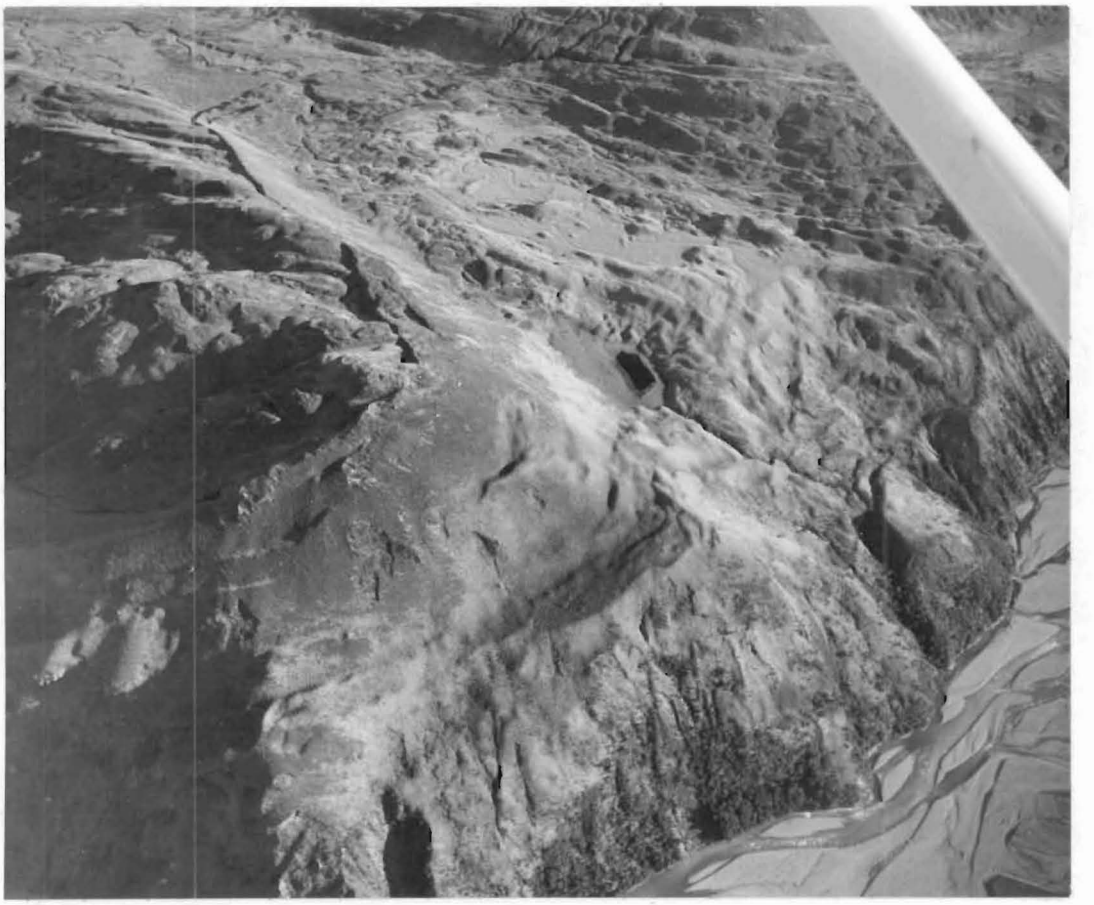
Figure 4.1 Rakaia - Lake Heron general site area map.


MATHIAS RIVER
Bull Spur Stream ← 1km
Washbourne Hut
Jellicoe Stream
Manuka Point Homestead
RAKAIA RIVER
Jagged Stream
Windy Tarn
Prospect Hill
883
670
2100
Washbourne Creek
Quagmire Tarn
Downs Hut
1530
1800
1800
1620
2000
2420
Marquee 2415
Bush Creek
Lake Stream
Leach Stream
Charlie Stream
Palmer Range
1980
1880
2000
1620
1920
1900
1980
Nell Stream
Ribbonwood Stream
Cameron River
Rocky Gorge
2000
1625
1900
1860
1470
2100
1210
Lake Heron
N
Site
Riverbed
Stream
Ridge
401 Spot Hgt. (m)
Moraine
Swamp
Outwash
Beech forest
Silver beech forest
Silver beech common
Podocarp forest
Scrub
Pine trees
Willows
0 1 2 3 4 5
Kilometres

a) Prospect Hill; showing Prospect Hill peak (left-centre), Lake Stream moraine (curving around the peak), Windy Tarn (right-centre), and Rakaia River. View : south-west.

b) Prospect Hill and Lake Stream Valley; showing Prospect Hill peak (foreground, left-centre), Quagmire Tarn (centre), Lake Stream moraine (right foreground), Lake Heron barely visible right of the conical hill in centre background. Windy Tarn is just out of view below right-centre. View : south.

Figure 4.2. Prospect Hill, Upper Rakaia Valley.



4.2.1 Quagmire Tarn (NZMS 1 S73 1st Ed. 1969 G.R. 664821; alt. 740 m; Fig. 4.3).

This site lies in a depression in Lake Heron moraine on the southern part of the Prospect Hill downlands. Quagmire Tarn is about 160 m x 60 m in size with a depth of over 2 m. The northern end is encompassed by an extensive peat bog which has the appearance of damming and encroaching upon the tarn. The tarn at this end is shallow (c. 10 cm) with a gently shelving bottom of soft yellow-brown mud in contrast to the deeper (c. 1 m) stone and boulder bottom of the southern end. There is no inlet stream and drainage is by seepage through the peat and by overflow via a channel at the south end. No aquatic vegetation is present except some *Potamogeton cheesemanii* plants in the shallows near the margins on which a few *Dacrydium bidwillii* bushes grow. The peat bog is moist and firm and is basically *Sphagnum* colonized by tussocks (*Chionochloa rubra* and some *Festuca novae-zelandiae*), and sedges with a variety of small native herbs (Appendix II). The gentle slopes immediately surrounding the tarn are covered with a *Chionochloa rigida*, *Festuca novae-zelandiae*/*Celmisia spectabilis* grass-forb community.

The coring site is located on the peat at the northern end of the tarn and about 2 m from the tarn's edge. The stratigraphy is described in Appendix I.

4.2.2 Windy Tarn (NZMS 1 S73 1st Ed. 1969 G.R. 654840; alt. 750 m; Fig. 4.4).

This site is also situated on Prospect Hill but on the

Figure 4.3 Quagmire Tarn site.
Coring site : x
View : east.

Figure 4.4 Windy Tarn site.
Coring site : x
View : north/north-east.

northern side and virtually in the Rakaia valley whereas Quagmire Tarn, some 2 km to the south-east, is more within the Lake Stream valley.

Windy Tarn lies in a small basin in Lake Stream moraine directly beneath the summit of Prospect Hill. The tarn is approximately 80 m x 30 m in size, floored with fine mud, and is about 2 m to 3 m deep, shallowing to about 0.5 m at each end. Its dark waters support a few *Potamogeton* plants at both ends. A compact bed of fibrous *Sphagnum* peat surrounding the tarn forms vertical banks and extends to the base of the surrounding slopes. A small outlet channel drains directly downslope into the Rakaia River. There are no inlet streams. A few clumps of sedge and an occasional *Chionochloa rubra* tussock grows on the tarn banks but the peat is mainly covered by a colonizing *Festuca novae-zelandiae* association derived from the surrounding slopes which also bear a few *Discaria toumatou* bushes. A 2 m to 3 m wide strip bordering the eastern margin of the tarn is bare of tussock and supports a low association of tough herbs. The immediate slopes are covered with *Festuca novae-zelandiae* grassland which is largely free of *Celmisia spectabilis*. A sward containing *Agrostis tenuis* grows between the tussocks.

The coring site is located in the middle of the herb-rich strip bordering the eastern edge of the tarn. The stratigraphy is described in Appendix I.

Prospect Hill and downlands is covered by a fire-induced grass-forb association in which *Celmisia spectabilis* is often dominant over the *Festuca novae-zelandiae* tussock,

forming a close carpet. Other grassland components include scattered patches of *Aciphylla aurea*, chest high *Chionochloa rigida* and some *Chionochloa rubra*, *Phormium cookianum* and many small herbs. Woody vegetation is not common. *Discaria toumatou* is occasionally abundant on alluvial surfaces and on some of the steeper faces where *Hebe salicifolia* and *Coprosma* spp. may also be present. Apart from a few cabbage trees (*Cordyline australis*) scattered on the open hillside, tree vegetation is restricted to very small forest remnants of broadleaved evergreen species (species list Appendix II) present in sheltered gullies where the ground fern *Polystichum vestitum* is usually abundant. A single silver beech tree with no adjacent juvenile plants stands in the tussock grassland about 1 km north of Quagmire Tarn, a little under 2 km from its nearest neighbours in the forest stand at Downs Hut. Large windfall dimples on Prospect Hill demonstrate the former presence of forest.

The mountains and hills in the vicinity of Prospect Hill are generally bare of woody vegetation (e.g., Fig. 4.1), a reflection of a fire history. A few modified forest remnants persist on low faces in small tributaries of the Rakaia and Rangitata catchments. Elsewhere, as in the Lake Heron basin and the upper Ashburton catchment, the vegetation is predominantly *Festuca novae-zelandiae* and *Poa colensoi* tussock grassland. *Chionochloa rubra* may be dominant on the valley floor; and on the lower slopes, fans, and terraces, *C. rigida* and *Celmisia spectabilis* are usually prominent. On higher slopes (above c. 1 000 m) snow tussock grassland dominated by *Chionochloa rigida* and *C. macra* form the main cover, which is often broken by extensive screes. Patches of

beech forest dominated by mountain beech with associated silver beech are present in some of the lower tributaries of Lake Stream. In general a sparse understorey of broad-leaved evergreen species may be present within the beech forest in moist positions of southerly aspect (e.g., Downs Hut forest, Appendix II). The habitats of silver beech in this area vary. Although occurring in the valley bottom and sheltered south facing slopes in the forest at Downs Hut, silver beech is present in dry and relatively exposed locations elsewhere (e.g.,Washbourne Creek, Nell Stream and Charlie Stream (Fig. 4.1). Silver beech distribution appears here to be related to the presence of ancient and degenerate silver beech trees, i.e., historical factors, rather than ecological. In the upper Rakaia Valley, mountain beech occurs in scattered patches from about the Wilberforce to just west of Manuka Point homestead, as well as in the Lake Stream tributaries. Mountain beech is also extensive in the lower Mathias Valley, at Mt. Algidus and in the lower Wilberforce where an apparently natural timberline* of 1 310 m is formed (Wardle, 1970). Pure mountain beech forest is present in the Harper River and small remnant patches are present in gullies about Lake Coleridge and in gully heads on the south bank of the Rakaia from Lake Stream down to the Rakaia Gorge. On the west bank of the lower Washbourne Stream (locally known as Thompson's Creek) previously unrecorded small stands of pure silver beech are scattered upslope and stand out from the scrubby patches of broad-leaved forest of *Griselinia littoralis*, *Pseudopanax*

* *sensu* (Wardle, 1965).

crassifolius, *Sophora microphylla* and *Hoheria glabrata*. (c.f. Holloway, 1954; Wardle, 1970). The silver beech stands there are mature and non-regenerating and have the appearance of being the remnants of a large patch of forest now obliterated by shingle slides.

In the uppermost reaches of the Rakaia, Mathias and Wilberforce valleys the forest is a mixture of types dominated by mountain totara (*Podocarpus hallii*), *Phyllocladus alpinus*, *Griselinia littoralis*, *Hoheria glabrata*, *Pseudopanax crassifolius*, with *Libocedrus bidwillii* in the Mathias and Wilberforce (Wardle, 1970), and (one small stand) near the Reischek Stream in the Rakaia valley. The forest merges at about 900 m into subalpine scrub consisting of varying proportions of *Phyllocladus alpinus*, *Dracophyllum longifolium*, *Podocarpus nivalis* and many other species as detailed in Appendix II.

More distant forests are: to the north-west over the Main Divide, the Westland montane and lowland forests of *Metrosideros umbellata*, *Weinmannia racemosa* and *Dacrydium cupressinum* respectively; to the north-east, the mountain beech forests of the Waimakariri catchment; to the south-west the isolated stands of depauperate podocarp-broadleaf forest and mountain beech forest respectively in the upper and middle (Potts - mid-Lawrence area) reaches of the Rangitata; and to the south-east, the beech forests of Mt. Somers where the Mt. Somers and Blondin Stream sites are located.

4.3 MOUNT SOMERS DISTRICT SITES

Mt. Somers (alt. 1 687 m, Figs. 1.1, 4.5, 4.6) is situated on the eastern outskirts of the Southern Alps overlooking the Canterbury Plains and forms the south-eastern corner of the large block of mountains between Lake Heron and the Rakaia Gorge. Blondin Stream is a small tributary of the South Ashburton River close to Mt. Somers and a little below the Ashburton Gorge. The valley is incised about 150 m into the high moraine surface of the Magazine glacial advance (H.W. Keene, pers. comm.). The Mt. Somers site is a high level subalpine site, while the Blondin Stream site is a low level plains site.

4.3.1 Mount Somers (NZMS 1 S81 2nd Ed. 1970 G.R. 858459; alt. 1 273 m; Fig. 4.7).

The site is one of several tarns in a bog complex on the flat top of one of the western summit ridges of Mt. Somers. Fig. 4.7 shows a small group of tarns within this complex.

The coring site is located in the centre of the long middle tarn. The stratigraphy is described in Appendix 1. The tarns are small (less than 6 m x 3 m in size), shallow (0.5 m deep), and with vertical sides of peat and mud bottoms. There are no inlet or outlet channels. Drainage is by seepage and overflow off the plateau. It is not entirely certain whether the bog complex is supplied by rainfall or springs. There is no evidence of a spring but the large area of wet flush downslope and the quantity of downslope drainage would seem excessive for the bog to

Figure 4.5 Mt. Somers general site area map.

LAKE HERON BASIN
Manuka Lake
963
Lake Emily
Mt. Somers Range
2092
1083
1696
Winterslow Range
Mt. Winterslow
1700
1409
1331
Clent Hills
1066
1366
River
Stour
Ashburton Gorge
Site
Mt. Somers
1680
Taylors
Stream
Alford Range
1463
1171
Taylors Stream
Woolshed Creek
Clandinl
stream
Site
Inverary
SOUTH BRANCH ASHBURTON RIVER
North Branch Hinds River
PLAINS
CANTERBURY
UPPER
Bowyers Stream

N

Site
Riverbed
Stream
Ridge
·401 Spot Hgt. (m)
Moraine
Swamp
Outwash

Beech forest
Silver beech forest
Silver beech dominant
Podocarp forest
Scrub
Pine trees
Willows

Kilometres

Figure 4.6 Mt. Somers; photo taken from above Blondin Stream site showing Blondin Stream Valley (foreground, left to right), Ashburton River (centre, left to right), Mt. Somers site location (arrowed). View : north-east.

Figure 4.7 Mount Somers site (in cloud).
Coring site : x
View : south-east.

Figure 4.8 Blondin Stream site.
Coring site : x
View : south/south-east.

be dependent solely on supply from rainfall.

A *Sphagnum-Chionochloa macra - C. rubra* community surrounds the tarns and extends 50 m or so downslope to the west. The bulk of Mt. Somers is covered with *C. macra* grassland which contains *Celmisia spectabilis* (abundant in places) a variety of small herbs and occasional small woody prostrates. Very little subalpine scrub is present on Mt. Somers (due most probably to past fires). A narrow belt of scrub (*Phormium cookianum, Dracophyllum longifolium, Hebe* spp., *Coprosma* spp., and ground ferns) occupies the moist southern bluffs above treeline. Alford Forest, with a treeline at about 1 070 m, occupies the eastern slopes of Mt. Somers and Mt. Winterslow to the north. The forest is mountain beech dominant with a small amount of silver beech and an understorey of broad-leaf species such as *Griselinia littoralis. Podocarpus hallii* and *Phyllocladus alpinus* occur infrequently, and stands of rata (*Metrosideros umbellata*) and a few *Podocarpus dacrydioides* trees are present in places. On the southern slopes of Mt. Somers strips of gully forest consist of pure mountain beech, but in the headwaters of Woolshed Creek on the western flank, forest is virtually pure mountain beech on the west bank but predominantly silver beech on the eastern slopes with a vigorously regenerating silver beech, fire depressed treeline at c. 900 m a.s.l..

4.3.2 Blondin Stream (NZMS 1 S81 2nd Ed. 1970 G.R. 803399; alt. 545 m; Fig. 4.8).

This site is a mire, some 40 m x 30 m in size, and is situated about 50 m above stream level on the top of a large block of moraine that has slumped into the valley. A small trickle supplied by seepage and slope wash runs into the mire and apart from a few downslope seepages from it there is little outflow. The mire surface is colonized predominantly by small tussocks rising 0.5 m above the ooze. The tussocks (*Chionochloa rubra*, *Cyperaceae* spp., *Sphagnum* spp.) support a little flax (*Phormium tenax*) and one or two specimens of stunted willow and *Coprosma* species, while the ooze in between is partly bare and partly covered with *Sphagnum* and other bryophytes, various algae, some *Potamogeton*, and patches of *Azolla rubra* in the pools.

The coring site is at the centre of the mire and the stratigraphy is described in Appendix I.

The surrounding countryside is covered with an induced tussock grassland of *Festuca novae-zelandiae*, *Poa colensoi* and introduced pasture grasses. An extensive thicket of matagouri (*Discaria toumatou*) and *Coprosma* species grows close by the bog and scattered bushes are common in Blondin Stream Valley. The whole area is grazed by sheep and cattle which have trampled the edge of the bog.

More distant vegetation includes the pines, willows, and English trees of Inverary homestead 2 km downvalley; the willow thickets in the Ashburton Gorge, 5 km to the north-west, where there is also a 25 ha plantation of pine; the farmland of the plains and the tussock grassland of the foothills with occasional remnants of broadleaved

evergreen forest in the foothills leading south (20 km) to the podocarp forests of Mt. Peel. The beech forest of Mt. Somers lies 7 km to the north-east.

4.4 LAKE SUMNER DISTRICT SITES

Lake Sumner (Figs 1.1, 4.9, 4.10) is the largest of a group of lakes which lie in the catchment of the Hurunui River within the Canterbury mountains, about 25 km from the Main Divide. Raupo Pond lies at the western ends of two of these lakes, Lakes Taylor and Sheppard. Springs Bog is some 20 km distant from Raupo Pond and is situated about 5 km upstream of Lake Sumner in the Hurunui Valley.

4.4.1 Raupo Pond (NZMS 1 S60 1st Ed. 1965 G.R. 681486; alt. 579; Fig. 4.11).

This site lies in the Sisters Stream valley within moraines of an un-named glacial advance correlated with the Poulter advance of the Otira Glaciation (Suggate, 1965). The pond is situated just outside the loop of moraine (of late Poulter age) which dams Lake Sheppard and upvalley from a belt of moraines left by ice of the same advance in the main valley (Fig. 4.9). A prominent moraine and outwash surface representing an advance of late Poulter age forms the Loch Katrine - Lake Taylor saddle about 6 km upvalley from the site. Large, mature, low-angle, coalescing fans deriving from sidestreams on the south side of the valley form the valley floor in the vicinity of Raupo Pond and one of them extends between Raupo Pond and Lake Taylor.

Figure 4.9 Lake Sumner general site area map.

MAIN DIVIDE

1590 1590 1650 1430 1390 1440 1830 1840 1860 1900

Springs Bog

Upper Hurunui River

701

LAKE SUMNER

Hope River

Hurunui River

1620 1700 1700 1580 1460 1300 1280 1260 1316 1220

Lake Katrine

Mason

Others

South Branch Hurunui River

Lake Sheppard

Lake Taylor

Conical Hill 1850

1006 915 884

Sisters Stream

Raupo Pond

1710 Studleigh Range 1810 1770 1760 1720

1380 1070 1390 Oronoko Range 1130 1230

South Branch Hurunui River

N

Site

Riverbed

Stream

Ridge

·401 Spot Hgt. (m)

Moraine

Swamp

Outwash

Beech forest

Podocarp forest

Scrub

Pine trees

Willows

0 1 2 3 4 5

Kilometres

Figure 4.10 Lake Sumner Basin; showing Sisters Stream Valley, Lakes Taylor and Sheppard, Raupo Pond, (left); Lake Sumner, Hurunui River (right). View : north-west.

V. C. Browne

Figure 4.11 Raupo Pond site.
Coring site : x
View : south-west.

Figure 4.12 Springs Bog site.
Coring site : x
View : north.

Raupo Pond therefore lies within deposits of early Poulter age and appears to have originally been a part of Lake Taylor now cut off by delta/fan infilling from a side stream on the south side of the main valley. Raupo Pond is relatively large compared with the other sites (approx. 500 m x 300 m) but well over half the pond is infilled on the western side with fine organic silt which supports a dense cover of raupo (*Typha orientalis*). The raupo is very dense, over 2 m in height, and contains no other plants except an occasional sedge. Depth of the open water is likely to be several metres. The outlet streams of Lake Taylor and Sheppard flow into Raupo Pond from the west and north respectively and a small stream draining hills to the south flows in on that side. The outlet on the eastern margin gives rise to the Sisters Stream. Dense willow and flax (*Phormium tenax*) are colonizing the raupo swamp about the inlet from Lake Taylor and mature willow trees grow along the southern banks of the pond. *Pinus radiata* shelter belts surround "The Lakes" homestead overlooking Raupo Pond on the flanks of Conical Hill on the western side, others grow nearby to the east and south and a small stand occurs near the outlet. The coring site is situated about 70 m from the southern shore in the raupo swamp in a position approximately central to the pond basin. The stratigraphy is described in Appendix I.

The immediately surrounding hills (c. 1 400 m) are covered with an induced *Festuca novae-zelandiae/Poa colensoi* tussock grassland and are generally bare of woody vegetation. Scattered bushes of *Discaria toumatou*, the introduced broom

Cytisus scoparius, and *Coprosma* spp. occur with some large patches of manuka (*Leptospermum scoparium*) present in gullies. The south-western side of Conical Hill carries a stand of mountain beech forest and other remnant patches in gullies occur up-valley. While patches of forest down-valley from Loch Katrine are pure mountain beech with no broadleaved evergreen understorey elements, those near Lake Sumner may contain red and silver beech in the gullies together with broadleaved evergreen species and rare small specimens of *Podocarpus hallii*. Occasional cabbage trees (*Cordyline australis*) are present throughout on the open hillsides. Arable land in the valley is usually sown with pasture grasses, lucerne, and turnips.

4.4.2 Springs Bog (NZMS 1 S53 4th Ed. 1972 G.R. 485593; alt. 604; Fig. 4.12).

This site is a raised *Sphagnum* bog (c. 400 m x 180 m) lying barely 100 m within beech forest in the upper Hurunui valley about 20 km northwest of Raupo Pond. The bog is situated on a low river terrace at the Mackenzie - Hurunui confluence and is named for the hot springs on the opposite side of the Hurunui valley. The bog surface is domed (the centre is about 1 m higher than the margins) and falls abruptly on the eastern and western margins to channels which drain eventually into the Hurunui River.

The bog surface is basically *Sphagnum* (*S. cristatum* dominant over *S. falcatulum* and *S. subsecundum*). Growing on it is the predominant *Dracophyllum palustre* together with *Pernettya macrostigma* and patches of *Drepanocladus*

fluitans and *Polytrichum formosum*. Growing on the bog edge are stunted trees and seedlings of mountain beech, *Coprosma* c.f. *parviflora*, *Myrsine divaricata*, the ferns *Hypolepis millefolium* and *Blechnum pennamarina*, *Carex coriacea* and *C. sinclairii*. A zone of pure mountain beech extends around the bog and a transect from the bog edge into the forest shows the forest composition to be mountain beech to 5 m, mountain and silver to 20 m where the normal silver-red beech forest types take over.

The coring site is located approximately in the centre of the bog and the stratigraphy is described in Appendix I.

Upslope, the forest composition changes through a mid-slope silver-mountain beech association at about 970 m to an upper-slope pure mountain beech forest extending from about 1 160 m to treeline (1 250 m - 1 400 m). Minor amounts of hardwoods and *Podocarpus hallii* and *Phyllocladus alpinus* are present especially at mid-slope. Further detail of composition is included in the description of the forests of Mac's Knob which are adjacent to Springs Bog in: 'The Beech Forests of Mac's Knob, Lake Sumner, Canterbury. Paper No.1.' School of Forestry, University of Canterbury, 1971. Above the treeline, a low subalpine scrub consisting of *Podocarpus nivalis*, and species of *Dracophyllum*, *Hoheria*, *Coprosma*, *Olearia* and *Hebe* becomes more common towards the Main Divide some 15 km upstream. The riverflats support the usual *Festuca novae-zelandiae/Poa colensoi* tussock grassland and matagouri (*Discaria toumatou*) thickets. Manuka (*Leptospermum scoparium*) becomes common near Lake Sumner.

Raupo Pond lies on the eastern outskirts of continuous montane beech forest whereas Springs Bog, closer to the Main Divide, is well within the montane beech forest. At Raupo Pond extensive beech forest is about 10 km distant on all points of the compass except the south-east quadrant where, apart from the forested headwaters of the Seaward River, scattered remnant stands of mountain beech give way to the tussock grassland of the foothills. The catchments adjacent to the Hurunui sites contain different types of forest. The forests of the Poulter and Esk catchments to the south are predominantly of mountain beech as in the Waimakariri but the Poulter forests also contain abundant red and silver beech. The upper Waiau catchment to the north contains a red-silver-mountain beech forest similar to that in the Upper Hurunui. To the east, away from the Main Divide this mixed beech forest is replaced by mountain beech. Downstream from Lake Sumner the vegetation is mainly tussock grassland with patches of manuka. Kowhai trees (*Sophora microphylla*) with some broadleaf (*Griselinia littoralis*) and lancewood (*Pseudopanax crassifolius*) line the banks and gorges. Where present on the hillsides, the forest is of mountain beech.

Over the Main Divide, the Taramakau River (which saddles with the Hurunui) forms the approximate boundary of the podocarp forests of central Westland with the beech forests of north Westland. These more distant Taramakau forests are predominantly podocarp, but those of the Otehake tributary are mixed beech, and riparian stands of mountain, red, and silver beech occur in the main

Taramakau valley. The general forest composition in the Taramakau catchment varies with altitude, grading from a dense subalpine scrub down into a *Libocedrus bidwillii*, *Podocarpus hallii*, *Hoheria glabrata*, *Dracophyllum traversii*, forest, which in turn grades into *Metrosideros umbellata* *Weinmannia racemosa* and *Dacrydium cupressinum* dominant podocarp forest at lower altitudes (Wardle, 1970): a pattern similar to the forests over the Divide from the Rakaia sites.

CHAPTER 5

MODERN POLLEN

5.1 INTRODUCTION

Some knowledge of the relationship between pollen rain and the parent vegetation is valuable in the interpretation of pollen diagrams. The reconstruction of vegetational history from the relatively recent (in geological terms) post-glacial pollen data is especially dependent on uniformitarian principles. Assumptions that the ecology of the species and species assemblages represented in the pollen diagrams approximates to that of the present day species must be made. Assumptions that the pollen production/dispersal relationship is unchanging within this period must also be made.

The pollen rain/vegetation relationship has received much attention. Empirical work on the purely statistical aspects of the relationship have been carried out mainly in the 1950's (e.g., Fagerlind, 1952). Later investigations have tended to concentrate on the ecological aspects of pollen representation, with the processes of pollen production, dispersal, and preservation receiving close qualitative and quantitative attention (e.g., Davis, 1963, 1967 a,b, 1968; Faegri & Iversen, 1964, 1975; Tauber, 1965). Considerable work has been done on various methods of comparison of modern pollen spectra with different measures of vegetation composition using a variety of natural and artificial pollen traps. The results have been variable.

More recently, broad studies of the modern pollen rain

such as Lichti-Federovich & Ritchie (1968) in the major vegetation zones of northern North America, and Webb's (1974) isofrequency studies in Michigan, have demonstrated good correspondence between vegetation types and modern pollen rain composition in a continental context. Similar results are obtained from sophisticated numerical analyses of modern pollen spectra (e.g., Birks, 1973; Birks, Webb & Berti, 1975; Richie & Yarranton, 1978).

In New Zealand, however, continental conditions do not apply. The mountainous nature of the islands and the variable weather conditions create almost infinite numbers of sub-regions amongst which conditions affecting pollen deposition will vary. The comparatively small scale of the vegetation zones and complex plant distribution patterns do not simplify pollen representativity. A fair knowledge of the ecology of the present day New Zealand vegetation is being achieved but very little is as yet known about qualitative and quantitative pollen production and dispersal by the various contributing species (but cf., Moar, 1970b; McKellar, 1973; Myers, 1973; Pocknall, 1978).

Modern pollen deposition within the study areas was not studied in detail. It was felt that interpretation of the pollen diagrams would be aided by the knowledge gained from a surface sample taken from the actual coring site for each diagram. The degree of pollen representation shown for the vegetation surrounding each site would help determine the characteristics of the site as a basin of deposition and also the provenance of the fossil pollen,

assuming that wind patterns were unchanging throughout the duration of the diagrams as would appear likely (Gage, 1965).

Table 5A lists the modern pollen data.

5.2 QUAGMIRE TARN AND WINDY TARN

In the pollen spectra from both these sites Gramineae pollen is overwhelmingly dominant. *Nothofagus fusca* type pollen, the next most frequent is only present at low values (c. 8%), and the remaining spectra are all minor constituents with the exception of Cyperaceae whose high values are a reflection of the on-site vegetation. The pollen spectra from these sites match each other fairly closely both in composition and proportion. The major exception is in Cyperaceae where the disparate values are almost certainly due to the greater abundance of sedge at the Quagmire Tarn site. It would appear that the two sites share the same modern pollen source areas and that the difference in site location means little, given that these sites are open and pollen deposition is uninfluenced by on-site woody vegetation.

The nearest sources for the *Nothofagus fusca* type pollen are the patches of mountain beech forest in the side creeks of Lake Stream and across the Rakaia at Manuka Point (Fig. 4.1). The record is believed to be representative of the modern disposition of beech forest considering the factors of over-representation (Moar, 1971; Myers, 1973) and the upwind position of the sites during

Table 5A Pollen from surface samples.

Results expressed as a percentage of total pollen counted excluding aquatics and spores. No data available for Blondin Stream.

(* extra-pollen sum)

(+ less than 1%)

	QT	WT	MS	RP	SB
Nothofagus fusca type	10	7	16	30	76
N. menziesii			1		10
Podocarpus	4	1	36	4	1
P. dacrydioides					1
Dacrydium cupressinum			2	1	1
Griselinia			+		
Phyllocladus	3	1	19	3	3
Dacrydium bidwillii type			10		
Coprosma	4	4	2	9	1
Myrsine				2	
Plagianthus			+		
Hoheria			1		
Dracophyllum	+				
Leptospermum			+	2	
Myrtaceae			+		
Coriaria	+	+	+		
Scrophulariaceae				1	
Gramineae	70	84	5	11	1
Compositae	1	1	3	5	
Umbelliferae				5	
Haloragis	4				
Acaena			+	5	
Caryophyllaceae	2				
Gentiana			+		
Ranunculaceae			1		
Cyperaceae	120*	30*	2*	4*	5*
Typha				22*	
Potamogeton		+*			
Lycopodium	+*		1*	+*	
Monolete spores	2*	7*	+*	3*	+*
Trilete spores	3*	1*	1*		
Salix				3	
Pinus				13	
Rumex		+			

the October-November flowering period (Wardle, 1970; Myers, 1973; McKellar, 1973) when winds from the north-west predominate. The frequencies of *Podocarpus* and *Phyllocladus* pollen are surprisingly low considering that *Podocarpus hallii* and *Phyllocladus alpinus* are dominant in the remnant forests of the upper Rakaia. Windy Tarn for example is directly exposed to down-valley winds and yet the two species are scarcely represented in the pollen spectrum. This may accord with the results of Moar (1970b) who has found the *Phyllocladus* component of subalpine scrub to be under-represented in subalpine grassland surface samples. Not only are the dominants of this upland podocarp forest virtually unrepresented but the complexity of forest composition is not demonstrated and *Griselinia littoralis*, one of the important species, is not recorded at all. Other important local vegetation components unrecorded or under-represented are: *Nothofagus menziesii* (as expected); *Pseudopanax crassifolius* especially prominent in Washbourne Stream; *Celmisia spectabilis**, a local grassland dominant; *Coriaria sarmentosa**, present in patches over Prospect Hill; *Discaria toumatou*, present on Prospect Hill and prominent in surrounding riverbeds; and *Pteridium esculentum* dominant on slopes below Windy Tarn and present in patches in the Prospect Hill grassland.

5.3 MOUNT SOMERS

The surface sample pollen spectrum from this high

* entomophilous

altitude site is problematical for it is not representative of the present day vegetation. The pollen spectrum is dominated by *Podocarpus* (36%) and *Phyllocladus* (19%), with *Nothofagus fusca* type (16%) and *Dacrydium bidwillii* type (10%) making up the bulk of the sample. The spectrum is puzzling, for the vegetation on and about Mt. Somers is predominantly tussock grassland with mountain beech forest (Alford Forest) and a small amount of subalpine scrub in which *Phyllocladus alpinus* is rare. Nowhere is there any *Podocarpus* forest, and only one *Dacrydium bidwillii* bush was found anywhere near the site.

For comparison, an alpine fell field site above beech forest and subalpine scrub on Travers Range, Nelson, yielded surface samples which have shown beech to be dominant and that "although there are considerable areas of *Dacrydium bidwillii*, *Phyllocladus alpinus* and *Podocarpus nivalis* growing in the subalpine scrubland on the Travers Range, the pollen of these wind pollinated shrubs is so infrequent as to suggest their near absence" (Moar, 1970b). These findings are in direct conflict with the Mt. Somers data. The possibility of *Podocarpus nivalis* being the source of *Podocarpus* pollen is discounted as the pollen values are totally disproportionate. *P. nivalis* is present above treeline at Mt. Somers but is rare and in any case the dominance of *Podocarpus* pollen (also *Phyllocladus* and *Dacrydium bidwillii* type) is merely a continuance of the pollen values of the podocarp forest phase in the diagram (Fig. 8.1). The absence of source vegetation for the prominent *Dacrydium bidwillii* type pollen values is almost

certainly due to recent fires for which there is considerable charcoal evidence in the site sediments (Appendix I). A similar situation exists at Swampy Hill, Otago, (McIntyre & McKellar, 1970).

The inconsistency of the surface sample data may be due to the sample having been taken from the topmost 0.5 cm of tarn sediment rather than a moss polster. Vertical mixing of sediment may have occurred. It is not likely that contamination has occurred during sampling as extreme care was taken to avoid this possibility. The smallness of the tarn precludes mixing by wave or current action, but disturbance of the sediments may happen during flooding of mudcracking, which has been observed in mid-summer when drying out of the tarn may occur.

Interpretation of the modern pollen spectrum with respect to the present day vegetation is not considered possible for this site.

5.4 BLONDIN STREAM

The surface sample yielded insufficient pollen for a count and many of the grains present were badly damaged. Grass and sedge pollen predominated. As far as may be judged the pollen is consistent with the surrounding grassland.

5.5 RAUPO POND

The pollen spectrum is dominated by *Nothofagus fusca* type pollen (30%) with *Pinus*, Gramineae, and *Coprosma* at moderate frequencies; and *Podocarpus*, *Phyllocladus*, Compositae, Umbelliferae, *Acaena*, and *Salix* at minor frequencies.

Nothofagus is over-represented for the Sisters Stream valley where mountain beech contributes only a measured 13% of the vegetation cover. There are two contributing factors - possible long distance dispersal from the Hurunui beech forests, and more importantly, the mountain beech forest of c. 100 ha area on Conical Hill barely 0.5 km to the north-west of the site. As a regional value however, the figure has some merit, as land to the north is heavily forested while land to the south is only sparsely forested. *Nothofagus menziesii*, prominent in the Hurunui forests, is not recorded.

Gramineae is vastly under-represented being masked most likely by the *Nothofagus fusca* type pollen. *Podocarpus* and *Phyllocladus* pollen are not considered to derive from the infrequent generally sub-canopy trees in the Hurunui forests, but rather to come from the podocarp forests of Westland. At 4% and 3% respectively they are considered to be over-represented. It is interesting to note that the pollen frequencies for these two pollen types are the same as those (4% and 3%) from the surface sample of Quagmire Tarn in the Rakaia where comparatively large source areas are considered under-represented.

The extensive, scattered low density scrub of the surrounding hillsides composed of *Discaria toumatou*, *Coprosma* and *Hebe* species with patches of *Leptospermum* and the adventive broom *Cytisus scoparius* in the gullies, is only really represented by the 9% *Coprosma* value.

Amongst the local and on-site vegetation:-

i) The *Typha* representation is considered to be surprisingly low at 22% (extra-pollen sum value), considering that the sampling site was situated within the *Typha* swamp.

ii) The flax (*Phormium tenax*) thickets at either end of the pond are not recorded at all.

iii) Willow trees present around the pond and near the sampling site are only represented by a 3% frequency.

iv) In direct contrast to the willow representation the small stands of *Pinus radiata* in the vicinity are greatly over-represented at 13%.

5.6 SPRINGS BOG

In the pollen spectrum from this forest-surrounded site *Nothofagus fusca* type pollen is overwhelmingly dominant and *Nothofagus menziesii* is seriously under-represented at 10%. This degree of under-representation is initially surprising for the site is set within the lower slope silver beech/red beech forest, and below the mid-slope silver beech dominant zone. However a marginal zone of mountain beech surrounds the bog, and it is probable that both the low values of *Nothofagus menziesii* pollen, and also the high values of *Nothofagus fusca* type pollen, are largely due to an abundance of local pollen from this source. This is assuming that pollen production is equal amongst beech species, as appears to be so within the limits of present knowledge (e.g., Manson, 1974; Wardle, 1974).

The small amounts of *Dacrydium cupressinum*, *Podocarpus dacrydioides*, *Podocarpus* and *Phyllocladus* pollen will be from west of the Main Divide with some *Phyllocladus* and *Podocarpus* pollen possibly coming from the infrequent specimens of *P. hallii* and *Phyllocladus alpinus* in the upper slope forests of the Hurunui. Little pollen evidence of the local bog vegetation is present and there is no evidence that the entomophilous *Dracophyllum palustre* is common on the bog. The marginal shrubs are represented, but the *Discaria toumatou* scrub/grassland vegetation of the extensive valley flats is not represented at all, despite the site being barely 100 m from the forest edge.

This site is valuable in showing that a pollen spectrum from a forest site can be distorted by edge effects from a marginal forest zone of atypical composition. It is valuable also in demonstrating that this edge effect, for beech at least, is so evident in a sample taken from near the centre of a clear site of some seven hectares area.

In summary, the pollen spectrum represents basically only the local forest, with some representation of the shrubs marginal to the bog, and with little indication of the bog vegetation itself. More detailed interpretation is unfortunately hampered by the lack of specific identification of *Nothofagus fusca* and *N. solandri* var. *cliffortioides* pollen.

5.7 CONCLUSIONS

It may be seen from these examples that at montane

sites the degree of relationship between the pollen rain and the vegetation about the site of deposition is very variable. The main causes of distortion of the composition of the pollen rain from an ideal representation appear to be:

i) "pollen dumping" by on-site forest trees depressing the proportional frequencies of other pollen in a sample,

ii) variations in pollen dispersal efficiency amongst wind dispersed pollen from different species,

iii) the inherent differences between wind dispersed and insect dispersed methods of pollination,

iv) the physical factors of site location.

In the data from this study, local site factors relating to both physiography and perhaps more especially to on-site forest appear to be the major cause of distortion of the pollen spectrum. It is important to realise when interpreting a pollen diagram, that the vegetative site factors especially may be changing throughout the history of the diagram, causing variations in pollen representation through time. Little is known as yet about the degree of representation of insect pollinated vegetation in New Zealand, and the ecology of pollen production and dispersal in wind pollinated plants constitutes a large gap in world botanical knowledge (cf., Faegri & van der Pijl, 1966, 1971). Transect sampling through plant community boundaries and along altitudinal gradients needs to be carried out in New Zealand. Blanket sampling also must be done to chart variation in composition of the pollen rain, in order to establish some basic knowledge of pollen dispersal in

mountain areas. Such knowledge will increase the validity of conclusions drawn from pollen diagrams.

CHAPTER 6

QUAGMIRE TARN

6.1 SUMMARY

In this diagram (Fig. 6.1)* a clear succession from a *Coprosma* scrubland grassland mosaic to a *Phyllocladus* dominant podocarp forest is portrayed. *Nothofagus menziesii* values rise late in the diagram to a prominence (60%) only seen elsewhere in Aranuian diagrams from Fiordland and western Southland (Harris, 1963; Cranwell & von Post, 1936). This short phase is succeeded by a grassland phase where elements of all previous forest types are represented as at the present day.

There are three radiocarbon dates:-

11 900 ± 200 yr B.P. (NZ 1652), 730 cm - 745 cm, dates the beginning of organic sedimentation.

10 000 ± 150 yr B.P. (NZ 1653) 660 cm - 690 cm, dates the change from scrubland/grassland to forest.

1 975 ± 90 yr B.P. (NZ 1654), 240 cm - 260 cm, dates the expansion of silver beech forest.

6.2 ZONE QT 1 750 cm - 690 cm

Coprosma pollen co-dominates with that of Gramineae. Monolete fern spores are prominent, a variety of shrub and herb pollen occurs, and tree pollen is present in low amounts.

The dominant *Coprosma* scrubland/grassland pollen in this zone represents the vegetation existing at the time of the final stages of the Otira glaciation in the area

* All pollen diagrams are in a pocket inside the rear cover.

(i.e., recession of ice from the Acheron - Lake Heron event, Soons, 1963; Burrows & Russell, 1975). The dominance of grass and *Coprosma* from the very beginning of the zone suggests that this vegetation (today's sub-alpine equivalent) was already well established when deposition began at the site. The declining frequencies of Gramineae and the rising frequencies of *Coprosma* in the initial few centimetres of the zone may represent either a widespread change from a former grassland vegetation or just a local point succession as the fresh surfaces were colonized. The overall trend within the zone however is that *Coprosma* is gaining dominance over grassland. The scrubland is likely to have been more diverse than appears in the diagram. In the early part of the zone minor scrub components achieve their highest frequencies in this diagram suggesting an initially rich composition. The grassland similarly is likely to have been richer than portrayed as many components are insect pollinated and will be greatly under-represented. Moderate values of Compositae throughout the zone (in contrast to the 1% representation of today's extensive *Celmisia spectabilis* at Prospect Hill) suggest that Compositae was a very important component of either grassland or shrubland. Intermediate values for monolete ferns following the same trends as the dominant Gramineae curve suggest that fern, possibly *Blechnum penna-marina* or *Polystichum vestitum*, was important in the same way as in similar communities today at Prospect Hill.

Tree pollen, present in low values, probably derived from both near and distant sources. *Phyllocladus* (*Phyllocladus alpinus*) and *Podocarpus* (mainly *P. hallii*)

sources must have been present extra-locally to allow for the sudden rise to high on-site values (*Phyllocladus* especially) shortly after the end of the zone. This interpretation is consistent with the modern pollen data for this site where present forest is poorly represented. *Dacrydium cupressinum*, rare in Canterbury (Franklin, 1968), displays the beginnings of a long-continued record throughout the diagram, almost certainly representing long distance dispersal from the extensive lowland rimu forests of central Westland (Holloway, 1954). The sporadic record of *Metrosideros* indicates a local presence, for in contrast to rimu, *Metrosideros*, being bird and insect pollinated, has been found to be seriously under-represented in the pollen rain (Moar, 1970b). *Nothofagus fusca* type, on the other hand is represented from the beginning in a virtually continuous trace record. *Nothofagus fusca* type pollen is generally over-represented in the South Island pollen rain, and evidence of long distance dispersal is common (e.g., Myers, 1973). The continuing presence of low values of *Nothofagus fusca* type pollen could derive from small local sources common to both Prospect Hill sites or a large, long distance source. In the absence of firm evidence of a large beech source in Canterbury at this time the likelihood of a local or extra-local source is preferred. Little is known about pollen dispersal in the valley systems of the Southern Alps, and the modern pollen data for the sites in the present study and at Cass (Moar, 1971) show that interpretation is not straightforward. The possibility of extra-local sources at this time in Lake Heron basin similar to those proposed for the Cass basin (e.g., Moar, 1971; Lintott & Burrows, 1973)

may be supported by evidence from the Harper River. There Moar (1973a) found mountain beech leaf fragments low in the podocarp forest phase and also a trace of *Nothofagus menziesii* pollen in the preceding *Phyllocladus* phase.

The fluctuations in pollen frequencies early in the zone at 735 cm, and the 20 cm of silt just above the base of the macromud, are of interest (Fig. 6.2). The 20 cm of grey silt with the upper boundary gradational over about 20 cm is almost certainly windblown silt derived from the Lake Stream advance of Rakaia ice. A temporary deterioration in climate causing the Lake Stream advance appears to have occurred soon (1 000 or so years) after the warming that caused the retreat of Lake Heron ice. This climatic deterioration may be represented at the 740 cm level, just below the base of the silt layer where the trends of the dominant pollen profiles are temporarily sharply reversed. The marked brief increase in otherwise falling Gramineae values and decrease in otherwise rising *Coprosma* values occurs before both curves stabilize. Change in other pollen curves lend support to this possibility. Compositae, perhaps a more sensitive indicator, has a marked dip in its curve and Cyperaceae drops before a temporary peaking coincidental with Gramineae. The sharp temporary reversal (in trends of vegetational sequence occurring in response to a general warming (Moar, 1966a; Walker, 1966) is consistent with a brief return to cold conditions and the silt, almost certainly derived from a glacial advance shortly after, supports this interpretation. However, despite this apparently consistent ecological

interpretation the possibility remains that the changes may be an artefact either of a proportional method of representation or of a random sample variation. Further confirmatory data are required.

Tree pollen spectra show little change although *Metrosideros* pollen is briefly prominent. A rich plant cover is suggested by trace appearances of shrub and grassland species in addition to the main profiles (e.g., *Pseudopanax*, *Aristotelia*, *Gentiana*, *Plantago*, and tetrads). The noticeable abrupt cut-off in the curves of many scrub and herb species at 730 cm is an artefact caused by a change in analysing interval from 5 cm to 20 cm. Many of the pollen frequencies at this point however, are declining and where the record resumes at the beginning of Zone QT 2, only low frequencies are present. This decline is possibly partly due to afforestation of the site, but most of the species involved (e.g., *Coriaria*, *Leptospermum*, *Haloragis*, Chenopodiaceae), are colonizers and their decline is probably as much a successional event as anything.

6.3 ZONE QT 2 690 cm - 670 cm

Dacrydium bidwillii type pollen values rise to 85% and drop to zero at the end of the zone forming a high, isolated peak.

Modern pollen rain studies have so far shown *D. bidwillii* pollen to be seriously under-represented (Moar, 1970b; this study, Quagmire Tarn). The high frequencies of *D. bidwillii* type pollen therefore may be taken to represent only a local dense cover of this vegetation although it was probably

extensive. The macrofossil record extending up to about 340 cm and the low pollen values throughout the diagram show that *D. bidwillii* has been on-site in low quantities throughout the whole history of the tarn. The significance of the phase, which is widespread in Canterbury is discussed in Chapter 12.

6.4. ZONE QT 3 670 cm - 260 cm

A long forest period in which high values of *Phyllocladus* pollen are dominant over *Podocarpus* pollen. *Phyllocladus* exhibits an overall decline throughout while *Podocarpus* rises to mid-zone and declines thereafter. All other pollen frequencies are very minor although *Dacrydium bidwillii* type and *Coprosma* maintain levels of about 5%. The presence of Gramineae and also *Nothofagus fusca* type pollen becomes more definite towards the end of the zone, and charcoal fragments also occur near the end of the zone.

The macrofossil record shows the site to have been within forest. Many more *Phyllocladus* cladodes than *Podocarpus hallii* leaves were found. The pollen profiles confirm and emphasize this local on-site presence of *Phyllocladus*-dominant forest. As far as present evidence allows (Moar, 1970b; Quagmire Tarn and Windy Tarn modern pollen data, this study), *Phyllocladus* appears to be under-represented unless present on-site when it is over-represented. This impression is strengthened by the absence of fossil cladodes until the 660 cm level where the *Phyllocladus* pollen frequency jumps to dominance. Site factors are no doubt influential, as in general there would seem to be nothing to prevent free dispersal of pollen

from the parent tree. More information on modern pollen dispersal of the species would be useful. Throughout this long zone, therefore, it is only possible to say that the site was forested with the on-site forest being *Phyllocladus* dominant. It is not possible to speculate on the *Phyllocladus/Podocarpus* proportions of the local or extra-local forest, although it is probable that *Phyllocladus* formed a dominant marginal zone as it does at similar sites today elsewhere in Canterbury. The sparse pollen records of typically under-represented forest species such as *Podocarpus dacrydioides*, *Griselinia**, *Aristotelia**, *Metrosideros**, *Pseudopanax**, *Pseudowintera**, and *Libocedrus* occurring throughout this forest phase, and the presence of unidentifiable angiosperm leaves in the sediments completes the picture of a more diverse forest than would appear from the diagram at first sight. The continued presence of pollen of *Podocarpus dacrydioides* and *Pseudowintera* in particular (now rare species in inland Canterbury), suggests that conditions were mild and moist.

Three interesting features occur within the zone:-

(i) 550 cm A sharp dip in the *Phyllocladus* curve accompanied by increased sand increment in the sediment.

(ii) 420 cm *Nothofagus menziesii* leaf.

(iii) 360 cm - 300 cm charcoal zone.

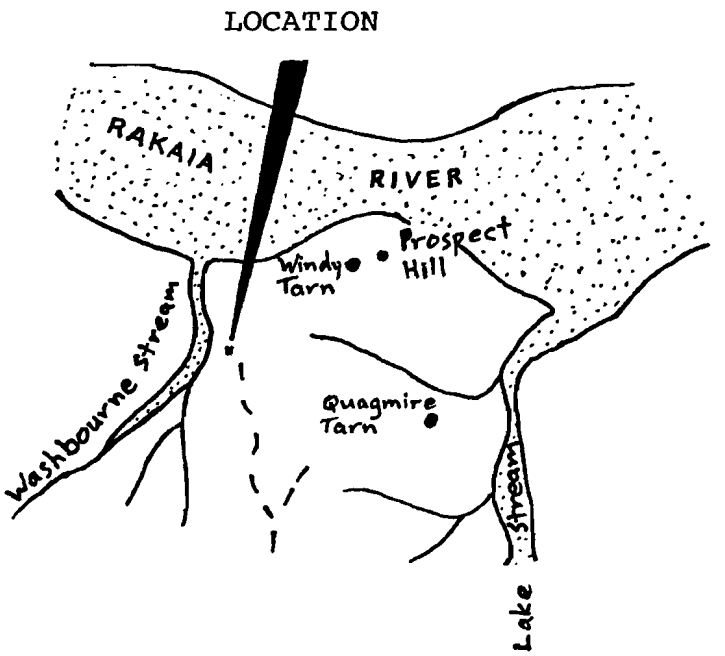
(i) At 600 cm to 540 cm sand becomes a noticeable component of the silty mud and *Dacrydium bidwillii* leaves are more frequent between about 600 cm and 570 cm. At 550 cm, with

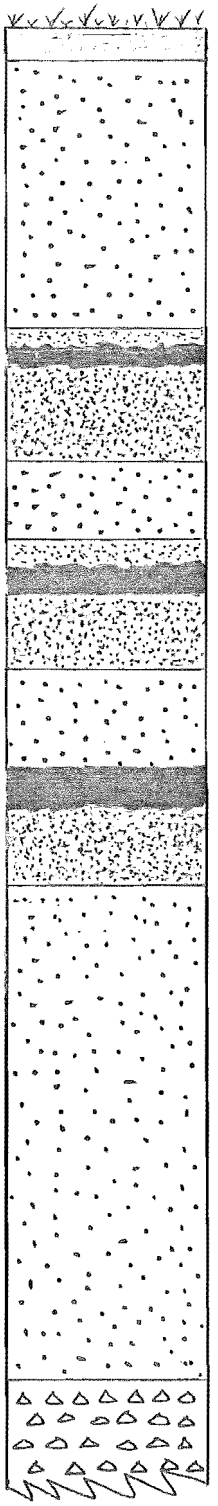
* insect (and bird) pollinated.

the exception of *Podocarpus*, there are brief fluctuations in the frequencies of most pollen types. The sharp valley in the *Phyllocladus* curve and accompanying peaks in *Dacrydium bidwillii* type, *Coprosma*, grass, and sedge values suggests a slight withdrawal of *Phyllocladus* from the site with an increase in the marginal vegetation zones of scrub, grass, and sedge. The possibility of the peaks in the scrub and grass profiles being artefacts associated with the drop in *Phyllocladus* values is appreciated. If this effect is purely representational then the greatest compensatory effect would be found in the pollen curve of the next most frequent pollen type - in this case *Podocarpus*. In fact the form of the *Podocarpus* curve at this point shows no such compensatory effect. The drop in *Podocarpus* values beginning at this point bears no relation to the deviation being discussed. Instead the scrub, grass, and sedge profiles show peaks, which if compensatory in nature, are quite disproportionate for these low frequency profiles. An ecological interpretation fits macrofossil, sediment, and pollen data, and is thought to be justified. A possible cause may be the event recorded by the lowermost of three buried soils at an exposure at Washbourne Creek (Fig. 6.3). This soil indicates that deforestation (possibly initiated by fire) occurred there followed by accumulation of silty sand. The drop in forest pollen at 650 cm at Windy Tarn (discussed in the following chapter, p. 105, may be a further consequence of this event but more evidence is needed for even tentative correlation.

(ii) The recovery of a *Nothofagus menziesii* leaf from 420 cm well before substantial evidence of this species in the

Figure 6.3 Buried forest soils exposure, lower Washbourne Stream, S73/639829. (C.J. Burrows pers.comm.)



STRATIGRAPHY	DESCRIPTION	^{14}C DATES (yr B.P.)
	10 cm modern soil	
	70 cm grey-brown sand	
pan	5 cm sandy silt with forest charcoals	860±50
pan	5 cm gley	N.Z. 3 941
	25 cm pale yellow-brown sandy silt loam	
	20 cm grey-brown sand	
pan	5 cm sandy silt with forest charcoals	5 830±130
	8 cm gley	N.Z. 3 942
	20 cm pale yellow-brown sandy silt loam	
	25 cm grey brown sand	
pan	10 cm gley	
	20 cm yellow-brown silt loam	
	130 cm grey-brown sand	
	stratified angular fluvio-glacial alluvium	

pollen diagram proves the local presence of the species hinted at by the sporadic pollen record long before its arrival in abundance on-site, which is documented by macrofossils at around 260 cm. (The relation of the leaf to the enclosing sediment excludes the possibility of it being a down-hole contaminant.) This circumstance has most likely arisen from the limited pollen dispersal range of *Nothofagus menziesii* combined with screening by the on-site forest. Considering this evidence and the lack of *Nothofagus menziesii* pollen in the modern pollen spectrum of this site, it is not unreasonable to assume local presence at least as far back as the earliest record of *Nothofagus menziesii* pollen at 570 cm. The implication is that the *Nothofagus menziesii* in the Lake Stream valley today either has a local relict origin, or, has originated from an early immigration from a nearby up-valley relict source (eg. Lake Heron Basin).

(iii) The presence of charcoal fragments at about 360 cm to 300 cm is not accompanied by discernible change in the pollen profiles. However, the summary diagram shows a sharp increase in shrubs then, and more especially herbs, at the expense of trees. The forest in the immediate vicinity of the site must have been unaffected. The rise of grass from trace values to 8% establishing the beginnings of the grass record, and the complete break at this point in the otherwise consistent monolete fern record, are thought to be related effects consistent with a fire occurring beyond the forested site. It may be that this charcoal is related to charcoal dated at 5830 yrs B.P. in a buried forest soil in the Washbourne Creek exposure (Fig. 6.3). However, interpolation of this date at 360 cm

results in gross variations in inferred sedimentation rate:-

680 cm - 360 cm 75 cm/1 000 yrs

360 cm - 260 cm 25 cm/1 000 yrs

260 cm - 0 cm 130 cm/1 000 yrs.

The uniformity of the sediment suggests that the sedimentation rate was fairly constant. An interpolated date of c. 4 000 yrs would be the earliest reasonable date on this assumption. If interpolation is based on a logarithmic time scale that assumes compaction of sediment with depth an even younger date (c. 3 - 3 500 yrs B.P.) results. The charcoal at 360 cm probably resulted from a later fire than the 5 830 yrs B.P. charcoal at the lower Washbourne Stream exposure.

Climate during this time was probably becoming drier. The best evidence for this is the long-term slow decline in (extra-local) *Podocarpus* values from a mid-zone maximum. Other indications such as the increased levels of Gramineae and the occurrence of fire may be of only local significance.

6.5 ZONE QT 4 260 cm - 130 cm

A short zone in which dominant *Nothofagus menziesii* pollen reaches a prominence (60%) not seen elsewhere in Canterbury or Westland. *Phyllocladus* values drop to moderate levels and *Nothofagus fusca* type values rise steadily from the low values late in Zone QT 3 to peak at the end of the zone at a moderate 17%.

With the exception of the single *Nothofagus menziesii* leaf recovered at 420 cm, the presence of *N. menziesii* leaves in consistent quantity does not begin until 300 cm - just before the sharp rise to dominance of the *N. menziesii*

curve. *N. menziesii* pollen frequency does not rise therefore until trees are virtually on-site. This confirms previous suggestions (e.g., Moar, 1971; McKellar, 1973) that *N. menziesii*, in contrast to *Nothofagus fusca* type pollen, is under-represented in the pollen record. The fact that the sudden rise in *Nothofagus menziesii* values and beginning of its macrofossil record occur shortly after the charcoal late in Zone 3 leads to the interesting possibility that fire may have been instrumental in releasing silver beech from competition with podocarp forest elements.

The drop in *Phyllocladus* frequencies as *Nothofagus menziesii* values rise is most likely due to on-site *Phyllocladus* being replaced by silver beech. *Podocarpus* values (probably extra-local) are unaffected and maintain a slow decline. The decline in local forest portrayed by the decreasing values of both *Nothofagus menziesii* and *Phyllocladus* towards the end of the zone and the rise in Gramineae values is probably due to a continued decrease in precipitation. Silver beech is highly frost and exposure resistant and is capable of regeneration and growth on extreme sites (Manson, 1974) but is intolerant of drought conditions (Williams & Chavasse, 1951). *Phyllocladus alpinus* is also susceptible to dry conditions (Wardle, 1969b) existing today as continuous vegetation in valleys where annual precipitation is about 260 cm or more (Lintott and Burrows 1973) (but note *Phyllocladus alpinus* and *Dacrydium bidwillii* presence in low rainfall areas in Central Otago (Bliss and Mark, 1974). Certainly the only regenerating silver beech stands in the study area today are those in sheltered gully locations.

The slowly increasing, and probably extra-local, values of *Nothofagus fusca* type pollen is similar to Windy Tarn

and interpretation of this for both sites is combined in Chapter 7.

Late in the zone, the increasing frequency of roots in the sediments, changing colour, rising Cyperaceae pollen values, and occasional *Phormium* pollen, combine to indicate shallowing of the tarn and the approach of the present *Sphagnum* peat developing from the north end.

6.6 ZONE QT 5 130 cm - 0 cm

A water gap occupies the lower half of the zone and charcoal fragments are present at the base of the zone (120 cm - 100 cm). The upper zone data (40 cm - 0 cm) show the prominence of grassland species. Tree pollen frequency is at low levels and generally declining; *Nothofagus menziesii* is absent and apart from *Coprosma*, scrub species are virtually unrecorded. The partial diagram QT 0 cm - 180 cm (Fig. 6.4), excluding Cyperaceae from the pollen sum has been constructed for this zone.

At the base of the zone at 120 cm the charcoal fragments present in the sediments; the ending of *Nothofagus menziesii* values; the abrupt drop in the slowly rising *N. fusca* type curve; and the beginning of the rise to dominance of grassland pollen; are all consistent with a fire occurring at the site. The reduced frequencies of tree pollen persisting in the upper zone are consistent with the representation of undestroyed extra-local and regional forest in the absence of on-site forest. It is likely that the approximately equal proportions of *Podocarpus* and *Phyllocladus* represented were a feature of the extra-

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local forest throughout its history.

In the upper zone (40 cm - 0 cm) Umbelliferae pollen was initially taken out of the pollen sum of the main diagram. Comparison with modern pollen showed an *Anisotome - Aciphylla* identity to be likely. Both genera are present in the grasslands of Prospect Hill. The pollen is probably predominantly *Aciphylla*. *Aciphylla* is a prolific pollen producer and is recorded by the early settlers (e.g., Barker, 1870 ; Kennaway, 1874 ; Acheson, 1961) as being a prominent and arduous impediment to travel in the backcountry grasslands - especially in the Rakaia - Ashburton district where today, at Prospect Hill it is still common. Fresh pollen of *Anisotome* and *Aciphylla* is sticky and pollination is by insects, often crawling beetles and flies (C.J. Webb pers. comm.). The range of pollen dispersal is likely to be very limited. In the absence of data from the water gap, the very high 40 cm value was regarded as gross over-representation. However in the equivalent zone in Windy Tarn (Zone WT 3) high values of Umbelliferae pollen assume the full curve only hinted at in Zone QT 5. Pollen distribution of *Aciphylla* may be more widespread than thought, with the suspected origin being wind distributed pollen from the large old dried-out inflorescences which are characteristic of the species present, *A. aurea*. *Aciphylla* is seen to have been a widespread and important component of the fire-induced Prospect Hill grassland.

The insect transported Umbelliferae pollen has been included in the pollen sum of the partial diagram QT 0 - 180 cm (Fig. 6.4). The additional dotted traces in this

diagram result from use of a pollen sum excluding the Umbelliferae pollen. The comparison shows significant changes in slope angle (e.g., *Nothofagus fusca* type, *Coprosma*), and more importantly trend direction (up or down) of profiles (e.g., *Podocarpus*, Compositae), resulting from the overall increase in values. The more complete Windy Tarn data were similarly treated (Fig. 7.2) to check this disturbing factor. The basic structure of the pollen curves is shown to remain unchanged.

The development of *Sphagnum* peat recorded in the sediments at the beginning of the zone denotes completion of infilling at the coring site. The dense concentration of roots indicate that the bog surface was well colonized by flora similar, probably, to the present day (Appendix II).

CHAPTER 7

WINDY TARN

7.1 SUMMARY

This diagram (Fig. 7.1), although very different in appearance from the Quagmire Tarn diagram, displays the same basic structure. However, being situated on moraine of the Lake Stream advance the site represents post-Lake Stream time only, and the earliest part of Zone QT 1 is not represented. The general sequence *Coprosma*/grass - *Dacrydium bidwillii* - *Podocarpus/Phyllocladus* forest - grassland (with minor beech) is demonstrated, but the main difference is the evidence for predominance of a floristically rich *Coprosma* scrub over the *Podocarpus/ Phyllocladus* forest in the forest phase. Other differences are the prominent values of *Dacrydium bidwillii* type pollen in the lower part of the zone and the very low frequencies of *Nothofagus menziesii* pollen.

7.2 ZONE WT 1 810 cm - 750 cm

Zone WT 1 correlates with that part of Zone QT 1 occurring after the band of silt attributed to the Lake Stream glacial advance. The vegetation represented is much the same, a *Coprosma* scrub/grassland. The main feature of interest is the abrupt rise in *Coprosma* from initial low values (10%) at the base of the zone soon after ice withdrawal.

As the high values of the *Coprosma* pollen in the Quagmire Tarn diagram show *Coprosma* to be well developed

locally at this time, the initial sharp rise in the Windy Tarn *Coprosma* curve from low values almost certainly represents colonization of the fresh Lake Stream moraine. This reinforces the same interpretation made for the earlier basal Zone QT 1 data and also suggests that *Coprosma* pollen has a limited dispersal range.

The presence of small amounts of pollen from the commonly under-represented forest elements - *Metrosideros*, *Weinmannia*, *Griselinia* and *Libocedrus*, at the very base of the zone, agrees with a similar occurrence (*Aristotelia*, *Metrosideros*) in the Quagmire Tarn diagram and probably derives from an extra-local source although the possibility of long distance transport from Westland cannot be entirely discounted. Trees probably occurred near to the receding glaciers at this time in areas such as the Lake Heron basin. Low levels of *Podocarpus*, *Phyllocladus* and *Nothofagus fusca* type pollen suggest a further diversity as discussed in Chapter 6.

7.3 ZONE WT 2 750 cm - 120 cm

This zone, although clearly delimited, is complex. No major dominants are present. Instead a number of pollen types, all at intermediate frequencies, show a variety of plant communities to have been present at this time. The overall impression is that the site was situated in scrubland. Peak values (88%) of *Dacrydium bidwillii* type at the beginning of the zone give way immediately to moderate *Podocarpus* and *Phyllocladus* frequencies. Scrubland pollen types then predominate for the rest of the zone.

Nothofagus values slowly increase toward the end of the zone and amongst the extra-pollen sum taxa, consistently high values of monolete fern drop at mid-zone and are followed by high Cyperaceae frequencies. The zone is divided into sub-zones WT 2a and WT 2b. Further subdivision is not warranted.

7.3.1 Zone WT 2a 750 cm - 700 cm

The early dramatic *Dacrydium bidwillii* type peak at 750 cm matches that in the Quagmire Tarn diagram in stratigraphic position, magnitude and brevity. It confirms the widespread presence of this phase on Prospect Hill and provides further evidence as to the regional nature of this phase of vegetation development, discussion of which is left until Chapter 12.

7.3.2 Zone WT 2b 700 cm - 120 cm

The major differences between Windy Tarn and Quagmire Tarn diagrams now become apparent.

(i) The broad peaks of *Podocarpus* (33%), and *Phyllocladus* (40%), fall to values of 15% or less, to remain at this level, and the pollen of associated broadleaved hardwood species is seldom recorded above the 400 cm level.

(ii) *Dacrydium bidwillii* type values rise directly after this early, brief dominance of *Podocarpus* and *Phyllocladus*, peaking at comparatively high values (34%) and continuing at substantial frequencies to the 400 cm level where records virtually cease. This is in direct contrast to Quagmire Tarn where *Dacrydium bidwillii* type frequencies fluctuate around the 5% level and extend right throughout the zone.

(iii) The resurgence of monolete fern spores, similar to the resurgence in the *Coprosma* values leads to very high values for much of the first half of the zone in contrast to the consistently low values at Quagmire Tarn.

(iv) Pollen values for all scrub components are substantially higher than the trace levels in Quagmire Tarn, with mid-zonal values of 30% (*Coprosma*), 15% (*Plagianthus*), 10% (*Muehlenbeckia*, *Myrsine*) being reached.

(v) Although the form of the *Nothofagus fusca* type pollen curve is essentially the same as that in Quagmire Tarn, the mid-zonal values of *N. fusca* type pollen are noticeably higher.

(vi) At this site only low values (less than 5%) of *Nothofagus menziesii* are present in the latter half of the zone.

i) Without more detailed macrofossil evidence the role of the *Podocarpus/Phyllocladus* forest is difficult to determine. It is possible that the site itself was forested at first with the initial high, combined pollen values of the two species (about 70%) representing local forest.

ii) The drop in frequencies of both *Podocarpus* and *Phyllocladus* pollen at about 650 cm and resurgence in *Dacrydium bidwillii* type values at 600 cm is not evident in the Quagmire Tarn diagram and probably results from a local event. At the equivalent depth in Quagmire Tarn (QT 550 cm - an extrapolated age of c. 8 000 yrs BP) the sand in the macromud, the small peak in *D. bidwillii* type, and the brief drop in *Phyllocladus* and following reduction in *Podocarpus* may be related effects, but the correlation is,

at best, tenuous. The drop in tree pollen values at Windy Tarn may be related to a probable fire event recorded by the oldest of three buried soils dated at an estimated 8 000 yrs BP at Washbourne Creek 1.5 km west of Windy Tarn (Fig. 6.3). The pollen curves are consistent with expansion of *D. bidwillii* upon release from competition with taller vegetation (Lintott & Burrows, 1973) although no evidence of fire was found in the sediments. Alternatively it is possible that the drop in tree pollen and rise in scrub pollen may be an artefact related to the change from inorganic to organic sediments which occurred at about the same time.

Conditions on-site subsequent to the proposed local deforestation were still favourable to *D. bidwillii* (wet enough and cool enough) although the concentration of roots in the sediments indicates a drying out of the tarn.

iii) The great predominance of monolete fern spores during this time, and the beginning of these values as the forest pollen frequencies drop, is entirely consistent with the present day expansion and persistence of the forest ground fern *Polystichum vestitum* after forest removal by fire and reversion to scrub. The grain cannot be precisely identified but *P. vestitum* is common near to the site today.

iv) The floristically diverse scrub which is predominant throughout much of this zone is in direct contrast to the long forest phase at Quagmire Tarn. The area about Windy Tarn today appears to be a drier site than Quagmire Tarn supporting a *Festuca novae-zelandiae* tussock grassland in contrast to the *Chionochloa rigida* about Quagmire Tarn This apparent dryness of site (probably a local soil factor)

combined with the very exposed and windy nature of the site may be the reason for the predominance of scrub at this time when forest was well developed elsewhere. Riverbed scrub pollen may have been a contributing factor. The presence of *Plagianthus* pollen (*P. betulinus*) in persistent and comparatively high values throughout this zone is of interest as this pollen type is rare in Aranuian diagrams from the Canterbury Alps. Further discussion is left until Chapter 12.

The early broadleaved hardwood records at Windy Tarn give evidence of a greater diversity of woody vegetation than is otherwise evident from the diagram. These records appear to be unaffected during the initial drop in forest pollen values (at WT 650 cm) and yet virtually cease at WT 400 cm whilst similar records remain unaffected at Quagmire Tarn. This is probably due to a combination of localized fire-related effects and the diverse mosaic nature of the scrubby vegetation which is envisaged as occurring at Windy Tarn during this time.

The 400 cm level marks a number of changes in the zone. In the pollen diagram substantial values of *Dacrydium bidwillii* type cease, broadleaved hardwood representation ends, high values of monolete spore begin a sudden drop, and the *Nothofagus menziesii* record begins not long afterwards. In the sediments a 4 cm band of fine sand-silt occurs at this point, followed by a diminishing silt component in the macromud.

The changes appear to have been caused by an event so local, or so minor, as not to have affected the pollen

frequencies of the main forest, scrubland, or grassland components, and at Quagmire Tarn there is no equivalent pollen or sedimentary evidence. The possibility that the sand-silt band at WT 400 cm is derived from a glacial advance is remote. Advances of Rakaia ice later than Jagged Stream were small, remaining in the head of the Rakaia valley. An event occurring at about this time in the vicinity of Windy Tarn which would be consistent with the changes at WT 400 cm is the fire recorded at Washbourne Stream dated at 5 830 yrs BP (Fig. 6.3). However, no charcoal was found at the WT 400 cm level and no conclusive correlation can be made. The fire represented by charcoal at QT 360 cm - 300 cm and not recorded at the Washbourne Creek exposure is probably linked with the grey silty mud and drop in fern values at around WT 350 cm in Windy Tarn; at which levels in both diagrams the Gramineae trace rises to 10% values.

In summary, two fires occurred on Prospect Hill between about 6 000 - 3 000 years ago.

One fire was radiocarbon dated at 5 830 yrs BP by charcoal at the lower Washbourne Stream and was not recorded at Windy Tarn (1.5 km distant) or at Quagmire Tarn (2.5 km distant). The other, at an estimated age of about 3 500 yrs BP was recorded by charcoal at Quagmire Tarn (360 cm - 300 cm), was unrecorded at Washbourne Stream, but was probably recorded at Windy Tarn by correlatable pollen evidence and by sedimentary evidence at WT 350 cm. The rise in Gramineae pollen to 10% frequencies at QT 360 cm and WT 350 cm suggests a fire widespread on the south-eastern flanks of Prospect

Hill and one which destroyed an amount of woody vegetation extra-local to both pollen sites (dominant pollen frequencies unaffected) sufficient to allow the increase in grassland represented by the increased Gramineae pollen values at both sites.

The history of fire at Prospect Hill at this time appears complex, with both local and more widespread fires occurring at different times destroying some, but not all, of the forest there.

For the latter part of the zone, the partial diagram Windy Tarn 0 - 400 cm (Fig. 7.2) excluding Cyperaceae from the pollen sum, has been constructed.

v + vi) There is little change in the within-pollen sum frequencies and the general predominance of scrub values continues, but with an increased Gramineae value of 10% beginning at 350 cm. *Nothofagus fusca* type values slowly increase to 15% at the end of the zone.

The extent and location of (forest of the) *Nothofagus fusca* (pollen-type at this time) (almost certainly mountain beech judging from present forest composition) is difficult to assess. *Nothofagus fusca* type pollen frequencies both at Quagmire Tarn and Windy Tarn indicate a slow expansion, but whether from near or distant sources is uncertain. From the present distribution of mountain beech forest in the Rakaia and Rangitata catchments (Fig. 2.11), an obvious origin is migration via the Harper Valley (where mountain beech has been present "for at least 5 000 years" Molloy & Cox, 1972) to Lake Stream - Lake Heron basin - Potts River into the Rangitata, from a source in the Waimakariri catchment. However, the low frequencies of *Nothofagus fusca* type pollen reaching a

minor peak of 27% at the end of Zone QT 4 does not appear to support this theory. Values of *Nothofagus fusca* type pollen early in the Windy Tarn record are generally higher than in Quagmire Tarn for the first part of the record. This, however, could be a function of it being a non-forested site (*contra* Quagmire Tarn at this time) rather than a function of nearness to source (i.e., Harper-Wilberforce). Much higher *N. fusca* type pollen values at both sites would be expected at this time if Lake Stream valley was a major migration pathway. Beech in the Lake Stream, Potts and Rangitata Valleys may have originated from refugia surviving the Otiran, possibly in favourable mid-slope positions in the frontal ranges and foothills (c.f. Lintott and Burrows, 1973).

The values of *Nothofagus menziesii* in contrast to Quagmire Tarn data are low, not exceeding 5%. Considering the postulated open nature of this site, and taking into account the under-representation of *N. menziesii*, these low values are taken to indicate a nearby extra-local pollen source as represented at Quagmire Tarn.

Amongst the extra-pollen sum spectra, the rise to high values of Cyperaceae pollen may in part be a fire related effect similar to the rise in Gramineae at this level, but is obviously linked with the appearance of *Sphagnum* peat in the sedimentary column and the development of bog vegetation late in the zone. The role of fire in the development of late Aranuian *Sphagnum* bogs is at present largely unknown. Origins of dark, steep-sided, peat walled mountain tarns of the Windy Tarn type are also not clear. At Windy Tarn the steep sides and central position of the tarn within the peat; the great thickness (2.5 m) and

compactness of the peat with its flat surface level with the tarn's outlet; the fact that the peat overlies lake sediment; all suggest a very slow concentric encroachment of peat on a tarn that has remained static at its present level during peat development. This contrasts with the explanations of Burrows and Dobson (1972 pp91, 92), who, for this type of bog suggest only a vertical development of peat with the size of the tarn remaining constant as the peat and tarn surface elevate. On Prospect Hill some small hollows in the moraine surface are completely floored with compact level peat and the Windy Tarn situation is seen as an intermediate stage in the closing over of a tarn of this type.

Taking into consideration the following points:-

i) the modern pollen data from both sites in which *Podocarpus* and *Phyllocladus* are equally represented;

ii) the matching frequencies of the *Podocarpus* and *Phyllocladus* curves at Windy Tarn (taken for the most part as representing off-site forest), and their stable relationship throughout the diagram;

iii) the general presence of pollen of commonly under-represented broadleaved hardwood elements;

it is felt that the composition of the general extra-local forest is fairly accurately represented, in contrast to Quagmire Tarn where local forest influences representation. Forest composition in the vicinity of Prospect Hill during Zone WT 2 time is thought to have been much the same as it is today in the upper Rakaia. The previously unsuspected prominence of scrub during this time, and the various influences of cool climate, glacial advances, natural fire,

and the diversity of the taxa involved, all contribute to a complex vegetation which was further affected by Polynesian and European man in Zone WT 3 time.

7.4 ZONE WT 3 120 cm - 0 cm

A short zone in which grassland pollen types predominate. Tree pollen values continue at reduced levels from Zone WT 2. *Nothofagus menziesii* records cease, and a greatly reduced scrubland is represented only by low frequencies of *Coprosma* pollen.

The small peak in *Nothofagus fusca* type values, the subsequent drop in tree and scrub pollen, and the rise in grassland pollen, are correlated with similar fire-induced changes at the Quagmire Tarn Zone 4/5 boundary. These further changes may be further expression of the fire which is recorded by the uppermost buried soil (containing charcoal) at the nearby lower Washbourne Stream, which is dated at 860 ± 50 yr BP (N.Z. 3941) (Burrows unpub.), (Fig. 6.3)[95]. This date is within the uncorrected time range of a group of radiocarbon dated charcoals from locations in the Cass basin which are postulated by Molloy (1977), to originate from one fire occurring at probably between 500 - 600 years ago, within the period of Polynesian settlement. The 860 radiocarbon yr BP charcoal date at Prospect Hill therefore, may represent an extension of the Cass fire episode.

In general this zone confirms impressions gained from the depleted Zone QT 4 data. The close agreement of the pollen profiles of both sites at this time, tends to

confirm the notion of forest having retreated from Quagmire Tarn, leaving that site as open as Windy Tarn. The overall similarity in the pollen spectra of both sites at this point, also suggests that there was little variation in the composition of the vegetation of Prospect Hill at this time, and that the grassland portrayed was widespread at least in the vicinity of Prospect Hill. Of particular interest in this zone is the Umbelliferae curve which shows that the high value at QT 40 cm was not just a solitary over-representation, as at first thought. The predominance of Umbelliferae pollen throughout most of this grassland zone and its presence in high values at Quagmire Tarn suggests, in the absence of modern pollen dispersal data, that *Aciphylla*, the most probable source, must have been very prominent indeed at Prospect Hill at this time.

The fluctuations in pollen spectra in the closing stages of the zone are thought to be fire-induced. The low Gramineae value at 10 cm is not an artefact caused by the high Compositae frequencies. The sharp dip in the Gramineae curve still remains when Compositae is excluded from the pollen sum and similar computation shows the preceding dip (60 - 40 cm) in Gramineae values not to be an artefact of the large Umbelliferae peak. Extensive burning of the backcountry grasslands by the early graziers was carried out in order to rid the holdings of the snowgrass (*Chionochloa spp.*) unpalatable to stock, *Aciphylla* (Spaniard) and *Discaria toumatou* (Wild Irishman), both serious hindrances to horse travel and stock movement. The declining Umbelliferae curve (as in Quagmire Tarn), the high following values of Compositae (most likely the fire

resistant *Celmisia spectabilis* of today's grassland) and the final steep rise to dominance of Gramineae pollen values to the present day in both Windy Tarn and Quagmire Tarn all fit this interpretation.

CHAPTER 8

MOUNT SOMERS

8.1 INTRODUCTION

The Mt. Somers site at 1 275 m altitude is today a subalpine grassland site. It is difficult to establish whether the site has always been above treeline. As Burrows & Greenland (1979) comment,there is little evidence that treelines have ever been higher than they are at present (in the Southern Alps). In all instances of logs above present treelines, fire is involved and the 'log line' is no higher than the undisturbed regional treeline. Treelines on Mt. Somers (c.1 200 m max.) are depressed by fire. There is no evidence in the form of stumps or logs above the treeline to provide an estimate of natural treeline altitude and the treelines of neighbouring ranges are similarly fire depressed (e.g., various authors in Knox, 1969). The nearest known natural treeline - Harper Valley, c.1 200 m (Molloy & Cox, 1972) is too distant from Mt. Somers and too near to the Main Divide to allow comparison. Judging by the altitude of the site and the N.A.P. content of the pollen sum, it is likely that the site was near treeline and situated probably within a subalpine scrub.

The diagram (Fig. 8.1) is relatively uncomplicated and portrays a change from an initial scrubland/grassland to a long podocarp forest phase. Interpretation however is not simple and discussion of the data is aided by the use of a supplementary N.A.P. diagram (Fig. 8.2).

The tree pollen dominant through most of the diagram is considered to be derived from lower altitude montane forest and is discussed using the main diagram. The scrub and grassland pollen, considered local in origin, is discussed using the N.A.P. diagram.

8.2 ZONE MS 1 115 cm - 95 cm

Zone 1 is a scrubland/grassland zone with the component pollen profiles exhibiting a remarkable prominence and diversity. Scrub pollen frequencies increase slowly as grassland pollen frequencies gradually diminish or remain at low levels.

The high Cyperaceae pollen frequencies are shown to be of local origin by the matching abundance of dense fibrous peat in the sedimentary column. Of particular interest is the falling c.f. Scrophulariaceae values which implies a former abundance of this type of vegetation. The significance is hampered, unfortunately, by a lack of more specific identification of this pollen type. For the greater part of the zone a *Coprosma* scrub/grassland is dominant. *Myrsine* appears to have been a prominent scrub component. Lesser amounts of *Plagianthus* and *Muehlenbeckia* occur towards the end of the zone. The Compositae, Umbelliferae *Plantago* and *Gentiana* records all demonstrate a diversity of subalpine grassland not evident at the site today. This is probably due to two factors; firstly the more humid summer conditions which probably obtained in early Aranuian times, and secondly, the recent fire history as evidenced by the charcoal in the upper part of the

sedimentary column, which would have depleted the grassland flora. The isolated occurrence of *Nothofagus fusca* type pollen at 105 cm and 95 cm may derive either from a nearby or a distant source. Its significance is later examined in the discussion of beech forest in Zone 2.

8.3 SCRUB/GRASSLAND IN ZONES MS 2 AND MS 3

The history of this subalpine scrub/grassland vegetation which continues throughout Zones 2 and 3 is now examined with the aid of the N.A.P. diagram (Fig. 8.2) which eliminates the masking effect of the pollen of the forest phase.

Excluding the local Cyperaceae it can be seen that there are two and possibly three phases of vegetation development portrayed. The final stages of a possibly *Hebe* (cf. Scrophulariaceae) phase is followed successively by *Coprosma* and *Dacrydium bidwillii* type dominance. The remaining curves are reasonably stable, showing perhaps more evidence of grassland at the beginning and end of the diagram than in the middle where a more diverse scrub vegetation is evident. It would appear that apart from the change in scrub dominants, and a certain loss in floristic diversity of grassland vegetation probably due mainly to fire, there has been little change in the nature of subalpine and alpine vegetation throughout Aranuian time.

The most striking feature, also evident from the main diagram, is the gradual rise in *D. bidwillii* type values throughout. This contrásts with the characteristic sharp peak in otherwise low *D. bidwillii* type values prior to the rise in *Phyllocladus*, which is present in other inland

Canterbury diagrams. However, none of these diagrams are from subalpine sites. The highest site previously studied, Woolshed Hill at c.1 000 m (Moar, 1971) is below treeline so comparison is not strictly possible. The only comparable site is from the summit of Swampy Hill (c.740 m), Dunedin, (McIntyre & McKeller, 1970), where a poorly drained plateau above podocarp forest supports a fire induced grassland in which logs of mainly *Dacrydium biforme* occur (I.C. McKellar pers.comm.). A recent fire history at Mt. Somers (and Swampy Hill) sites is almost certainly the reason for the general absence of the fire susceptible bog dacrydia in the present day subalpine grassland there. The gradual increase of *Dacrydium* vegetation throughout Aranuian time portrayed in the Mt. Somers diagram (and also Swampy Hill) differs from the pre-forest phase peak in *D. bidwillii* in other Canterbury diagrams. This gradual increase is thought to be a consequence of soil leaching and poor drainage, developed as precipitation and temperature increased in the early Aranuian.

8.4 ZONE MS 2 95 cm - 85 cm

For discussion of the forest pollen spectra, the main diagram is used. Plots using an A.P. sum merely emphasize trends already evident in the main diagram.

Phyllocladus values rise to over 50% as those of *Coprosma* and other pollen types drop. *Podocarpus* frequencies are low.

The rising *Phyllocladus* curve records the spread of *Phyllocladus* before the establishment of *Podocarpus* forest

and the *Dacrydium cupressinum* record shows that extensive rimu forests were being established at the same time in Westland. This brief phase of *Phyllocladus* forest most probably results from the presence of local refugia whose presence is suggested by the low *Phyllocladus* values throughout Zone 1.

In the sedimentary record the change from a Cyperaceae peat to macromud shows the beginning of the tarn's history and the presence of *Potamogeton* and *Myriophyllum* pollen confirms the presence of free water.

8.5 ZONE MS 3 85 cm - 0 cm

Podocarpus values rise to a long-continued dominance. *Podocarpus dacrydioides* and *Dacrydium cupressinum* records are typical of long distance dispersal which for the commonly under-represented *P. dacrydioides* need imply only an extra-local source at the base of the mountain. The *Nothofagus fusca* type pollen record does not begin until half-way through the zone and rises only in the last 10 cm.

It is difficult to assess the relationship between *Podocarpus* and *Phyllocladus* from this subalpine diagram. In the present day forests at Mt. Somers *Phyllocladus* is not common. At Mt. Peel, where *Phyllocladus* is unrecorded, the upwards altitudinal sequence in the podocarp-broadleaf forest is through lowland *Podocarpus dacrydioides/P. spicatus/ P. totara* forest - *P. spicatus/P. totara - P. hallii* - broadleaved evergreen angiosperms (Allan, 1926; Kelly, 1972). The long continued co-dominance of *Phyllocladus* and *Podocarpus* pollen values at Mt. Somers probably results from an

altitudinal zonation, with *Phyllocladus* forming a zone above podocarp forest. A mixed or mosaic forest would be a more probable interpretation were the site a low altitude one (as for example Windy Tarn). The presence of silt in the sediments up to 85 cm is taken as evidence that the mountain was not fully vegetated until that time. The beginning of the record of *Podocarpus dacrydioides* pollen at the base of the rise in *Podocarpus* values is seen as indicating the expansion of lowland podocarp forest in the area. The source for *Podocarpus* colonization of the hill slopes is therefore seen as being lowland plains forest.

In the beech record the early, isolated, and relatively high (5%) values of *Nothofagus fusca* type pollen that occur in Zone 1 before the main podocarp phase, are similar to early beech records at Kettlehole Bog and Woolshed Hill sites at Cass (Moar, 1971). They may derive from local refugia as proposed for the Cass region (Lintott and Burrows, 1973), but more data are needed for confirmation. The later, continuous beech record, beginning at 40 cm in the podocarp forest phase, is probably an effect of a spread of beech forest which has raised proportional pollen representation to a recordable level. The very late rise in *Nothofagus fusca* type pollen frequencies beginning at 10 cm accompanied by only a slight decrease in *Phyllocladus* and *Podocarpus* implies that the present extensive beech forest is of very recent origin. This contrasts with much earlier expansions of beech forest at inland sites to the north, e.g., Cass (intermontane site) between 8 000 and 5 000 years ago (Moar & Lintott, 1977), Rubicon Creek (upper plains site) c. 6 300 years ago (Moar, 1973b). This in turn

suggests that despite the early beech record at 100 cm the frontal ranges at Mt. Somers at least, did not act as extensive beech refugia during the Otira glaciation and that beech did not expand there early in the Aranuian. However it is likely that the apparently late rise in beech and near absence of *Nothofagus menziessii* pollen is a consequence of unknown factors of site and/or fire. The possibility of occurrence of small sheltered hillslope beech refugia similar to those at Mt. Peel today (Allan, 1926), is not excluded. The survival of podocarp forest with only very small mid-slope beech enclaves at Mt. Peel is probably due to a moister local climate, compared to Mt. Somers, where drier conditions and possibly fire may have been responsible for the competitive replacement of podocarp forest by beech forest. Understorey composition at Mt. Peel and Mt. Somers is very similar.

The macromud continuing from Zone 1 implies a relatively high organic input (i.e. woody vegetation, rather than grass). This, as well as the early cessation of silt and the rising *Phyllocladus* values at 90 cm probably indicates the early establishment of a closed tall vegetative cover round the site - scrub rather than grass. Open water appears to have continued until the 54 cm level where the red-brown root zone surmounted by dark red leaf bases and soil horizon characteristic of *Schoenus pauciflorus* indicates a lowering of water level. If there was no change in outlet level then this lower water level, allowing sedge growth at the coring site (centre of tarn), may be indicative of decreased precipitation.

The major change in sediment type occurring at 50 cm where silt replaces the macromud above the *Schoenus* zone is caused by fire. The silts contain fine charcoal fragments. The two *Sphagnum* bands within the silts represent halts in silt deposition. The cause of these interruptions in silt deposition is most probably the revegetation of the unstable areas, denuded by fire, allowing the on-site establishment and growth of *Sphagnum* bog. The absence of charcoal in the top 5 cm of the lower silt tends to support this interpretation. Reconstruction of the site history from the top 50 cm of sediments suggests that a major fire episode was followed by two lesser fire periods and that revegetation of the source areas of the silt allowed the growth on-site of *Sphagnum* bog after the first two fire periods. The final top 5 cm of micromud indicates a return to shallow water conditions with grassland surrounding the tarn rather than the earlier shrubland.

It is difficult to reconcile this reconstruction with the pollen evidence as the pollen curves show little change during this period and give little hint of the location and extent of the fire episodes. The only possibly related effects are the beginning of the *Nothofagus fusca* type record at 40 cm soon after the beginning of the first silt episode; and, at 10 cm or less, the rise in *N. fusca* type values, the drop in *Dacrydium bidwillii* type, and the cessation of the minor records of *Podocarpus dacrydioides*, *Libocedrus*, *Muehlenbeckia*, *Myrsine* and *Umbelliferae*. More data are needed to link the beginning

of the *Nothofagus fusca* type curve with fire and the changes at 10 cm are not firm enough evidence.

The level site, its high altitude and lack of inlet stream, the amount of silt deposited (nearly 50 cm), the absence of organic input, the development of *Sphagnum* during stable periods, and the final deposition of micromud, all point to near-complete destruction of local vegetation. However, no major effect is apparent in the pollen diagram. The pollen curve of the lowland forest species (e.g., *Podocarpus dacrydioides*), the spectra of the montane forest species, and the spectra of the subalpine scrub and grassland vegetation, all remain unaffected. The very late rise in *Nothofagus fusca* type and the end of the *Podocarpus dacrydioides* record, especially, may signify the destruction of lowland podocarp forest. Correlation with the diagram from the nearby Blondin Stream site (Fig. 9.1) is not possible and there is no charcoal evidence at that site but by B.S. 80 cm the dominant podocarp record there had virtually ceased.

It is possible that the montane podocarp forest pollen of this period was derived from forest surviving on the steep moist southern faces of Mt. Somers and Mt. Winterslow (whose present beech forests have largely escaped recent European fires). The silts and charcoal could have been derived from the drier north west slopes of Mt. Somers but it is possible that they were windblown from much further away (e.g., in the Lake Heron basin). The general absence of forest in the Lake Heron catchment and on the north western slopes of Mt. Somers (where today a single mature beech tree survives in the midst of an extensive protective

boulder patch) supports both these views. The general absence of *Dacrydium bidwillii* from the present sub-alpine grassland also indicates that recent fires, at least, must have involved the site. The fire history within the environs of the Lake Heron basin is likely to be complex.

CHAPTER 9

BLONDIN STREAM

9.1 SUMMARY

This diagram (Fig. 9.1) covers the latter part of the podocarp forest period and the beginnings only of a grassland period where presumably beech forest also attained its maximum extent. Data is lacking for the top 80 cm, due to fluid sediments and unsatisfactory surface samples.

9.2 ZONE BS 1 200 cm - 100 cm

Dominant *Podocarpus* values (40 - 45%) in the first half of the zone gradually decrease to 24% at the end of the zone as scrub and grassland values increase. The *Nothofagus* record (*Nothofagus fusca* type and *N. menziesii*) begins at mid-zone with *N. fusca* type values fluctuating about a 10% value. Rising values of Cyperaceae record the development of on-site swamp.

The dominance of *Podocarpus* pollen (*P. spicatus* with some *P. totara/P. hallii*) shows the site to be within a *P. spicatus* dominant podocarp forest, probably much the same as the present day forest at similar locations at Mt. Peel (Allan, 1926; Kelly, 1972). The prominence of pollen of scrub and forest marginal shrubs (*Coprosma*, *Plagianthus*, *Phyllocladus*), making up about half the pollen sum, most likely reflects the presence of a marginal shrub band although this community would have also been present in the valley of Blondin Stream.

In the lower part of this diagram, the presence of *Weinmannia* pollen in comparative abundance (7%) is of interest, as it is the first substantial record of this pollen type in a Canterbury diagram. The possibility, shown by the declining record, that this tree was formerly more abundant is of further interest as detailed in Chapter 12. The general absence of *Podocarpus daerydioides* pollen from this podocarp forest phase is surprising. It was expected from the long continued presence of this pollen type during the podocarp phase of the Mt. Somers diagram, and from the presence of little pockets of *P. daerydioides* lowland forest nearby at Alford forest and (more so) at Mt. Peel, that *P. daerydioides* pollen frequencies at Blondin Stream would be far more prominent. *P. daerydioides* must have been restricted to the forests of the more extensive low-lying river terraces of the Ashburton River at the base of Mt. Somers and not present to any extent in the more steeply graded tributaries. Site factors such as the masking effect of marginal trees at this relatively small site may have had a contributing effect.

The *Phyllocladus* pollen is not thought to derive from a *Phyllocladus* component of mixed *Podocarpus/Phyllocladus* forest as present in the upper Rakaia. At Blondin Stream, *Phyllocladus* values do not match the declining *Podocarpus* values at the end of the zone as in other Canterbury diagrams (e.g. Windy Tarn; Lake Henrietta, Moar, 1973a) but remain relatively steady, matching instead the *Coprosma* curve. Intermediate values of *Podocarpus* (40%) indicating off-site presence of forest, and the variety and abundance

of scrub pollen, contribute to show *Phyllocladus* to be present on the bog margin (as occurs today elsewhere in the Canterbury mountains) and comparatively unaffected by the factors (decreasing precipitation) affecting the podocarp forest. Judging from the high *Phyllocladus* pollen frequencies in the Quagmire Tarn diagram,which represent on-site forest, a relatively narrow band of *Phyllocladus* is likely to have been present at the Blondin Stream site. Unfortunately the pollen record does not extend back far enough to show what role *Phyllocladus* played at this upper plains site,prior to the podocarp phase.

The *Plagianthus* curve tends to match that of *Podocarpus*. The decline in *Plagianthus* (the forest species *P. betulinus*), half way through the zone,coincides with the start of the decline in *Podocarpus* values and is most probably linked with the decline in podocarp forest. Its immediate drop to low values is probably due to a more restricted ecological tolerance and shorter life history than *Podocarpus spicatus*.

Beginning at 150 cm the decrease of *Podocarpus* values towards the end of Zone 2 as well as the gradual increase in *Leptospermum* and the overall increase in Gramineae, is seen as probably being due to a further drying in climate as already evidenced by the *Weinmannia* decline. It may be attributed perhaps more directly to the series of fires which are recorded by charcoal in the sediments of the Mt. Somers site and which begin about this time (assuming correlation of the beech curves in both diagrams). The gradual increase in *Leptospermum* and Gramineae could be a reflection of both a trend towards the drier,lowland plains

Podocarpus spicatus/Leptospermum ericoides mosaic forest type and of fires. The development of swamp vegetation as demonstrated by the proliferation of roots in the macromud and the sequential *Phormium* and Cyperaceae pollen curves is likely to have also been influenced by fire and climate. Charcoal is present at the base of surface *Sphagnum* root zones in several bogs in montane Canterbury (e.g., Kettlehole Bog and Lake Hawdon, Cass, (Lintott & Burrows, 1973); Quagmire Tarn, Rakaia,(this study)) and the transition from free water to swamp at this level below the outlet, points to decreased precipitation at this site where the inflow derives only from the local slopes.

Low beech values (*Nothofagus fusca* type, 10%; *N. menziesii*, 1%) beginning as *Podocarpus* values decline, almost certainly represent the same general source as the Mt. Somers records and indicate an extra-local expansion favoured by drier conditions and possibly triggered by fire, judging from the Mt. Somers evidence. Further discussion of beech is continued in Zone 2.

9.3 ZONE BS 2 100 cm - 0 cm

Gramineae pollen frequencies rise to dominance accompanied by rises in Compositae and trilete spores. Pollen frequences of woody species decline.

The rise to dominance of Gramineae pollen beginning at 100 cm, accompanied by increasing frequencies of Compositae and sharp decreases in pollen of all woody species except *Nothofagus*, is a change common to many diagrams in Canterbury (e.g., Prospect Hill; Cass, Moar

1971), that is recognized as being due to fires of probable Polynesian origin (Molloy, 1977).

There is further evidence for fire (Molloy, in Harper 1972) in the general area of Mt. Somers on the upper plains about the Rangitata River. Soil charcoal evidence suggests that apart from a small area opposite Peel Forest, the environment (dry climate and shallow stony soils) was hostile to true forest and that a dense and more or less continuous kanuka (*Leptospermum ericoides*) scrub existed prior to Polynesian fires. Radiocarbon dating shows these fires to have been widespread on the upper plains about the Rangitata 500 - 1 000 years ago.

The low values of beech pollen show that beech has not occupied the site within the duration of the diagram. Judging from the presence of totara logs in Blondin Stream valley and the odd remnant pockets of broadleaved angiosperm species in the district, beech has not been present here in more recent times either. The extension of Alford beech forest a few kilometres onto the plains as recorded by Torlesse in 1849 (Maling, 1958) appears to have been a local feature in that area. The consistent low values of *Nothofagus menziesii* pollen beginning shortly after the *Nothofagus fusca* type curve is not likely to represent the silver beech component of a mixed beech forest as in the Raupo Pond diagram but rather an expansion of remnant patches. The only major occurrence of silver beech in the area today is a discrete stand within mountain beech forest at Mt. Somers directly across the Ashburton river from Blondin Stream.

The beech pollen in both Blondin Stream and Mt. Somers diagrams is likely to be from the same general source, but the relationship between the two curves cannot be ascertained because of the disparate nature of the two sites and lack of radiocarbon controls. Although reliable correlation cannot be made it is likely that both beech records begin at the same time. The combined data however are insufficient to allow any firm conclusions to be made concerning the various roles of local refugia versus southward migration of the northern beech forest, or drying climate, or fires, in determining the detailed forest history of this area.

The picture obtained is that the lowland podocarp forest in the immediate vicinity of Mt. Somers was eliminated by drying climate and fire and was replaced by grassland while Mt. Somers itself remained forested or at least partly so - a conclusion reached independently from the Mt. Somers data. Beech forest in the area was probably located in the lower foothills and expanded most likely as a result of fire as the podocarp forest declined but was never on-site at either Blondin Stream or Mt. Somers sites.

Blondin Stream data shed no further light on the origin of mountain beech forest in the Mt. Somers area or on the origins of silver beech in the Mt. Somers or Upper Rakaia districts. Nevertheless pollen evidence from this site shows that expansion of both *Nothofagus fusca* type and *N. menziesii* forest components occurred at the same time and that sources appear to have been discrete rather than mixed. There is also evidence that *Weinmannia* was a

prominent component of the early podocarp forest at the base of the foothills at Mt. Somers indicating an earlier, wetter period than at present.

CHAPTER 10

RAUPO POND

10.1 PREFACE

Raupo Pond is situated beyond moraines of the late Poulter glacial advance (Poulter 2) and within moraines of early Poulter age (Poulter 1) (Fig. 4.9). Deposition of the sediments sampled was thought to have begun in late Otiran time beginning after the early Poulter glacial event. The great depth of sediment (14 m) and the basal glacial clays supported this idea. However the pollen diagram conforms very well with the Canterbury Aranuian pollen zones of Moar (1971) which cover post late-Poulter time. A possibility existed of revegetation beginning in the mid-Poulter interstadial and continuing largely unaffected by the late Poulter advance. Conforming with this possibility was the distance of the site from the centre of South Island glaciation (and from the Main Divide), and the limited extent of late Poulter ice in the Sisters Stream Valley (and more especially in the Waiau catchment further north (Suggate, 1965)).

In the absence of a basal radiocarbon date establishing the beginning of revegetation an extrapolation was made to try and clarify the issue. A reasonably constant sedimentation rate was implied by the general uniformity in texture and density, and the great thickness of the micromud which extends down to c. 1 200 cm. Extrapolation beyond the 6 990 ^{14}C date at 675 cm based on a constant sedimentation rate of 1000 yrs/m appeared reasonable.

The resulting timing of the rise in *Podocarpus* pollen values at about 1 050 cm (c. 10 500 yr B.P.) is consistent with present knowledge, and the tailing off of (rapid) inorganic sedimentation at 1 300 cm - 1 200 cm is consistent with the timing of the end of the late Poulter glacial advance (Suggate, 1965).

If the diagram is accepted as spanning post-Poulter time then a stratigraphic time gap exists between the beginning of the sediments sampled and the moraines of early Poulter age upon which the site is situated. Organic sedimentation in Raupo Pond may have begun on periglacial sediments deposited during the mid-Poulter interstadial, but a more likely explanation and one taking into account the basal blue-grey glacial clay, is that formation of Lake Taylor and Raupo Pond did not begin until post-Poulter time. This could be due to stagnant ice of the early Poulter advance having persisted in its terminal position through the mid-Poulter interstadial with ice subsidence and lake sedimentation not beginning until late- or post-Poulter time. A similar situation occurs to the south in the Poulter valley (Gage, 1958) and possibly also in the Boyle valley to the north (Clayton, 1965).

10.2 SUMMARY

A clear sequence of vegetation types is depicted in this diagram (Fig. 10.1) A *Coprosma* scrub/grassland/fern association is followed by a succession of forest types: a short *Phyllocladus* phase, and two longer phases of

Podocarpus and *Nothofagus* respectively.

10.3 ZONE RP 1 1 400 cm - 1 300 cm

Coprosma values rise steeply at the beginning of the zone from co-dominance with Gramineae, to peak at mid-zone, where values for monolete ferns also peak. Gramineae values drop throughout the zone from a position of initial co-dominance. Other scrub and grassland pollen spectra show little change with the exception of *Coriaria* which drops to trace levels at mid-zone.

The rise in *Coprosma* and fern, and the decline in grass, represents either a general change from a grassland vegetation existing prior to this record or more probably (judging from the Prospect Hill data), a local succession of colonizing vegetation on the surrounding moraine. Certainly the picture presented - grassland with Cyperaceae and the nitrogen fixing colonizer *Coriaria* giving way to a *Coprosma* dominant scrubland with fern, fits the pattern of known succession on moraines (Stevens, 1968; Burrows, 1973; Wardle, 1973) although not necessarily the time scale. Low values of tree pollen ranking in order of their later dominance (*Phyllocladus* 7%, *Podocarpus* 2%, and trace of *Nothofagus fusca* type at base), show elements of these forest types to be within pollen dispersal range at this time.

The gradual change in the sediment from clay to silt, and the subsequent root zone, clay band, and Cyperaceae-type vegetation horizon at the end of the zone, demonstrate that shallow water was present and that local vegetation was generally sparse.

10.4 ZONE RP 2 1 300 cm - 1 100 cm

Phyllocladus pollen predominates and moderate values of *Dacrydium bidwillii* type pollen are limited to the zone. Moderate values of *Coprosma* also occur, *Podocarpus* pollen frequencies are low, and grassland and shrub pollen drops to trace levels.

The rise in *Phyllocladus* pollen frequencies to dominance (80%) and the drop in *Coprosma* values to low levels records the establishment of *Phyllocladus* forest. The moderate *Dacrydium bidwillii* values throughout the zone, and early small peak as *Phyllocladus* assumes dominance, shows that in contrast to other inland Canterbury sites, *Dacrydium bidwillii* did not appear to form a prominent pre-forest phase but was probably present only as a pond-margin component.

The rise in podocarp values from Zone 1 shows that *Podocarpus* (mainly *P. spicatus*)* was expanding, probably within Sisters Stream valley and approaching the site judging by the local presence shortly after in Zone 3. The trace presence of *Metrosideros* and *Podocarpus dacrydioides* at the end of the zone tends to confirm this interpretation. Moderate levels of *Coprosma* pollen probably derive from a scrub belt surrounding the pond. The trace amounts of *Nothofagus mensiesii* pollen at the beginning and the end of the zone most probably derive from the same source as the *N. fusca* type - by long distance dispersal probably from northern forests.

In the sedimentary record the varying concentrations of roots and complex banding suggest shallow water while

* see p. 45 para. 3

the change from silt to organic mud, coincident with the rise in the *Phyllocladus* curve shows that a stable plant cover had been achieved. The fine nature of the mud and the general paucity of macrofossils is thought to be a result of the distance of the coring site from shore in this large pond, rather than being evidence against the pond being surrounded by forest. The presence of high levels of *Isoetes* throughout much of the early diagram, implying free water, tends to support this view.

10.5 ZONE RP 3 l 100 cm - 600 cm

Phyllocladus drops to low levels as *Podocarpus* rises to a long period of dominance, pollen frequencies of *Phyllocladus*, *Coprosma*, and *Dacrydium cupressinum* are low and the *Nothofagus* record begins late in the zone.

The rise to dominance of *Podocarpus* values records the expansion and probably widespread development of podocarp forest (*P. spicatus* dominant over *P. ferrugineus*; *P. hallii/P. totara* also present) in the Sisters Stream valley. The presence of *P. dacrydioides* pollen at low values, and limited to this zone together with the broad-leaved, evergreen angiosperm genera *Weinmannia*, *Griselinia*, *Pseudopanax*, and *Pseudowintera* in particular, shows that forest probably surrounded the tarn and suggests that conditions were moist. The micromud present throughout this zone (and the next) is typical of deepwater conditions, being of great thickness, of consistently fine grain-size, and structureless - lacking in roots and current bedding. Low frequencies of *Coprosma* pollen and occasional

presence of *Tupeia* records the continuing presence of scrub around the margins of the pond. The *Dacrydium cupressinum* record begun in zone 2 assumes unusually high values (up to 10%) throughout this zone (and the next) if the pollen originated in Westland. At Springs Bog, 20 km nearer the Main Divide, *D. cupressinum* values are steady at only 2-3%. The general form of the *D. cupressinum* profile at Raupo Pond, extending throughout the diagram over several periods of major change in vegetation and at consistently low values,is typical of long distance dispersal of a forest tree and is similar to that in other Canterbury diagrams. It is possible that the higher frequencies are a function of the comparatively large size of the open pond as compared to Springs Bog. Nevertheless the values on the whole are thought too large for an entirely western origin. An unconfirmed sighting of *D. cupressinum* near Lake Sumner and the occurrence of *D. cupressinum* not far distant at Mt. Grey (Burrows, 1969b) may support the possibility of an extra-local origin. The sharp fall in *Podocarpus* values and the abrupt ending of representation of sub-canopy angiosperm elements (also *P. dacrydioides*) at the end of the zone demonstrates the replacement of podocarp forest near the site by beech.

A major event causing the decreasing presence of silt over some 200 cm (a period of possibly 2 000 years) occurred at the 700 cm level. A search of the literature revealed nothing of seismological events occurring in this active area at about this time and there is no evidence of glacial

advances in the Sisters Stream catchment to which the silt could be attributed. Although no charcoal fragments were found, a possible interpretation is that a fire occurred in the drier hills within the catchment of Raupo Pond, perhaps influencing the spread of beech in these areas where it would be more competitive than on the wetter valley floor.

A similar fire may be responsible for the silt increment of the micromud extending from 1 125 - 900 cm.

10.6 ZONE RP 4 600 cm - 0 cm

Nothofagus fusca type pollen rises steeply to a long period of dominance and falls in frequency near the end of the zone where pollen frequencies of grassland and swamp vegetation increase to low or moderate values. Low values of *Nothofagus menziesii*, *Podocarpus*, *Dacrydium cupressinum*, *Phyllocladus*, and *Coprosma* pollen, continue throughout the zone. *Ascarina* pollen is present.

Podocarp forest was replaced by beech but the *Podocarpus* pollen frequencies, continuing throughout the zone at about 20%, show that replacement was not complete. Podocarp forest (mainly *P. spicatus*) probably remained as patches in favoured locations. The continuing absence of pollen of sub-canopy elements (and *P. dacrydioides*) suggests that podocarp forest was entirely replaced by beech on the valley floor about the tarn.

Unfortunately the proportions of mountain to red beech pollen, and thus the composition of the forest, cannot be determined as the pollen types are practically indistinguishable (Harris, 1956, 1957.) Forest today is virtually absent

from the Sisters Valley. The few small stands of forest present are solely of mountain beech. These may represent a former mountain beech dominant forest, in contrast to the mixed forests of the upper Hurunui valley. Nearby, red beech with minor amounts of silver beech only occurs in small amounts in pockets of forest around the west end of Loch Katrine. The recovery of a red beech leaf from 490 cm in the sediments, at the beginning of the dominant beech pollen profile, suggests that red beech in the past may have been an important if not dominant component of the valley forest, similar perhaps to the tall stands of pure red beech on the other side of the Brothers Range at the outlet of Lake Sumner.

The consistently low *N. menziesii* record extending back almost as far as the dominant *N. fusca* type values, and unaffected by what is taken to be the on-site arrival of *Nothofagus fusca* type forest, is typical of long distance dispersal. In contrast to *N. fusca* type pollen, for silver beech this need not imply great distance, but probably indicates an extra-local presence. Similar low silver beech pollen values at Windy Tarn in the Rakaia valley contrast with high on-site values at Quagmire Tarn. Silver beech was never a major component of the adjacent forest about Raupo Pond judging from the substantial proportion of silver beech pollen in the Springs Bog modern pollen data. The source most likely would have been the silver beech component of the beech forests of the upper Hurunui valley.

The trough in the *Nothofagus fusca* type curve at 100 cm is not easy to account for. It may possibly be

a site effect linked with the approach on-site of the *Typha* swamp or it may be due to contamination from mixing of the fluid sediments during sampling.

Trace amounts of *Ascarina* pollen are virtually restricted to this zone and almost certainly derive from the lowland forests of Westland where *Ascarina lucida* is common. *Ascarina* pollen is widely dispersed by wind (Moar, 1970b, 71; Mildenhall, 1976; McGlone & Moar, 1977).

The absence of data from the top 90 cm restricts interpretation, but it is known from old records (Acheson, 1961) that the valley vegetation was already tussock grassland when first discovered by Taylor and Sheppard in the 1860's. The Hurunui valley was a major Maori routeway to Westland and Burrows (pers.comm.) has found abundant beech charcoal in soils of the tussock grassland/scrubland at Loch Katrine. It is almost certain that Maori fires were responsible for forest decimation here as in the Cass area (Molloy, 1977). The surface sample pollen spectrum certainly reflects a reduction in beech forest and an increase in grassland species.

In the extra-pollen sum record, the sequential curves of *Potamogeton*, *Isoetes*, Cyperaceae and *Typha*, together with the leaf remains in the sedimentary column, demonstrate the approach on-site of *Typha* swamp.

CHAPTER 11

SPRINGS BOG

The period covered by the diagram (Fig.11.1) lies completely within the beech zone (Zone RP4) of the Raupo Pond diagram and depicts a stable period of mixed beech forest. The timespan is therefore considered to be less than 7 000 years.

The occurrence of leaves of mountain and silver beech throughout the sedimentary column shows that the site was always in forest and the forest was composed of mountain and silver beech, as today. The absence of the more tender leaves of red beech is not thought to indicate the absence of this species. Aerobic conditions at the bog surface appear to quickly destroy red beech leaves while the tougher leaves of the other species survive.

The diagram is composed of pollen spectra from four main sources - the on-site beech forest, the developing bog (*Sphagnum*, Cyperaceae), the bog margin vegetation (*Coprosma*, fern, Gramineae, herb), and the podocarp forest of Westland over the Divide in the Taramakau River (*Dacrydium cupressinum*, *Podocarpus* spp., *P. dacrydioides*).

The information available from this diagram is limited but valuable. It is especially unfortunate at this mixed beech forest site that the role of red beech cannot be determined. The following points are of interest.

(i) In this stable site environment the unchanging proportions of the beech pollen spectra are seen as providing important evidence that the fossil pollen spectra

relate directly to the modern pollen spectrum and that the principle of uniformitarianism may be used with some degree of confidence at least with respect to beech species. The eleven analyses making up the diagram provide a mean frequency of 88% (range - 84% to 93%) for the beech pollen using a pollen sum excluding aquatics, spores, and Cyperaceae. This figure may be regarded as a first approximation to the fixing of a value for on-site beech forest. If 85% is taken as a working measure, it can be said with some confidence that any beech pollen value over 85% denotes on-site forest. (Average distance of coring site from nearest forest edge = 60 m).

(ii) The unchanging values of the long distance transport pollen suggest that there has been no major changes of the Westland forest types over the Main Divide in the Taramakau River during this time. This might be taken as suggesting little change in the "beech gap" boundary there.

(iii) There is no evidence of fire at this site either in the sediments or in the pollen spectra. Man-made fires do not appear to have extended up the Hurunui valley.

CHAPTER 12

DISCUSSION

12.1 INTRODUCTION

Detailed examination of the pollen diagrams has shown the individual sites to have had diverse histories. The relation of these site histories to the present knowledge of forest history is now shown by inclusion of these data in a general appreciation of the historical development of vegetation in montane Canterbury.

The influence of local site factors in vegetation and pollen representation is perhaps greater than previously recognized (e.g., Quagmire and Windy Tarns) and so it has been felt that the interpretation of a pollen diagram should be presented in two steps. First an individual, detailed site history reconstruction, followed secondly, and separately, by an examination of the relation of the site history reconstruction, in broad terms, to the known pattern of regional vegetation history. Diagrams from montane sites should not be thought of as being directly representative of the regional vegetation history. In the process of reconstruction of vegetation history in areas as large as for example a major river catchment, although there is little need at present for individual site histories, such histories will be required in the future when more detailed palaeo-environmental reconstructions will be developed from a higher density of sites. Workers in New Zealand have tended to generalize too quickly on the historical state of the vegetation from pollen evidence

without fully accepting that the pollen record, particularly in montane areas, may be restricted in representation.

The site histories are summarized in Tables 12A, 12B, 12C. These histories, as well as adding further evidence to the data accumulating on the Aranuian development of vegetation and climate in the South Island, also provide information on:-

i) the timing of forest expansion in montane Canterbury,
ii) the spread of beech on the eastern side of the alps,
iii) the history of the isolated silver beech stands in Canterbury,
iv) the incidence of fire in the areas studied.

The apparent differences in the overall trends of vegetation development relate to the present day distribution of forest types. The diagram from the Raupo Pond site, within the beech forest of the northern South Island, fits very well with the five pollen zones of Moar (1971). On the other hand the diagrams from Prospect Hill and Mt. Somers sites, which are near the southern fringe of the main northern distribution of beech forest and subject to considerable fire histories, do not conform so well, exhibiting no distinct beech phase and displaying substantial variations in the record of the main podocarp phase. In general, however, the pollen diagrams illustrate a development soon after retreat of glaciers from their last Otira maxima from grassland/scrubland through scrubland to forest, with grassland becoming prominent again in recent times, a pattern conformable with that established for Canterbury by Moar (1971).

Table 12A Prospect Hill, summary of site histories.

PROSPECT HILL SUMMARY

Date yr B.P.	Reconstruction of Events	Pollen & Sedimentary Evidence	
		Quagmire Tarn	Windy Tarn
120	Fires, early European graziers pasture improvement	c. 10 cm; steep rise in Gramineae	10 cm; steep rise in Gramineae
	Fires, pre-European	40 cm; steep decline in Umbelliferae	40 cm; 10 cm silty peat steep decline in Umbelliferae
860 ^{14}C (Burrows unpub.)	Fire, charcoal soil at Washbourne Stream, depletion of Prospect Hill forest and scrub, grassland predominant	120 cm; charcoal, drop in *Nothofagus fusca* type frequency, rise in grassland pollen	120 cm; drop in *N.f.* type frequency, rise in grassland pollen
	Mountain beech continuing to expand but not a major forest component on-site	*N.f.* type rise to low peak at 130 cm	*N.f.* type low peak of 120 cm
1 975 ^{14}C (240 - 260 cm)	Expansion of *Nothofagus menziesii* (probably partly fire induced), *N.m.* on-site at Q.T. at expense of *Phyllocladus*, not at W.T.	320 cm; 1st definite *N.m.* record 260 cm; *N.m.* rise in dominance	350 cm; beginning of *N.m.* record
c. 3 500	Fire in the Prospect Hill vicinity	360 cm; start of lift in grass values to 10% 360 - 300 cm; charcoal in sediments	350 cm; grey silty mud, grass values lift to 10%, drop in high monolete spore values
5 830 ^{14}C	Fire, middle charcoal soil at lower Washbourne Stream		400 cm sand/silt band with silt component in following sediment
	Climate slowly becoming drier	Slow decline in *Podocarpus* increasing beech and grass	Increasing beech and grass
	Beginning of slow expansion of mountain beech forest	400 cm; beginning of definite *N.f.* type record	550 cm; beginning of definite *N.f.* type record
c. 8 000	Deforestation event - brief increase in *Dacrydium bidwillii*, scrub and grass at Q.T., deforestation at W.T., with greater increase of *D. bidwillii* than in Q.T. and rise in ground fern, deforestation at Washbourne Stream subsequent to a stable period represented by lowermost mature soil. Scrub begins a long period of prominence at W.T.	560-540 cm; sand component in sediment 550 cm; brief drop in *Phyllocladus* later decrease in *Podocarpus*, small peak in *D. bidwillii* type and scrub spectra.	c. 650-600 cm; drop in forest pollen, rise in monolete fern, *Coprosma* scrub values become prominent 600-400 cm; *D.bidwillii* type resurgence greater than in Q.T.
pre 9 520, ^{14}C (Burrows & Russell, 1975)	Jagged Stream glacial event		Silts (post-*D.bidwillii* type peak) extending to 600 cm
10 000 ^{14}C (660-690 cm)	*Dacrydium bidwillii* phase marking overall warming of climate, beginning of forest vegetation, on-site *Phyllocladus* dominant podocarp forest at Q.T., *Podocarpus/Phyllocladus* forest near W.T.	690-660 cm; *D. bidwillii* type peak 670 cm; steep rise to dominance in *Phyllocladus*, rise in long continued *Podocarpus*	750 cm; *D. bidwillii* peak 700 cm; initial high *Phyllocladus* and *Podocarpus* values
11 900 ^{14}C (730-745 cm)	Brief deterioration in climate leading to Lake Stream glacial advance Lake Stream glacial advance and retreat, colonization of Lake Stream moraine	740 cm; brief sharp reversal in *Coprosma* and grass curves, etc. 730-690 cm silt	800 cm; bottom of hole, blue-grey glacial clay, rise in *Coprosma* over initial grass
pre 11 900	Retreat of Lake Heron ice, colonization of moraine with *Coprosma* scrub-grassland and fern, probable presence of extra-local pockets of podocarp/hardwood forest and more distant beech pockets	750 cm; bottom of hole, blue-grey glacial clay pollen records	

Table 12B Mount Somers district, summary of site histories.

MOUNT SOMERS DISTRICT SUMMARY

Reconstruction of Events	Pollen & Sedimentary Evidence			
	Mount Somers		Blondin Stream	
Declining upper plains podocarp forest further reduced by fire and replaced by grassland while Mt. Somers remained forested or partly so.	5 - 0 cm;	Macromud with fine charcoal fragments.	100 cm;	Steeper decline in *Podocarpus* values and decline in associated scrub species frequencies; abrupt rise in Gramineae and accompanying rises in grassland spectra.
	15 - 5 cm;	Silt with fine charcoal fragments; *Sphagnum* band at 12 cm; no change in trends of dominant *Podocarpus* and *Phyllocladus* curves despite silts and charcoal presence.		
General spread of beech forest in the area, possibly triggered by fire, at a time when conditions were causing decline in the upper plains podocarp forest.	40 cm;	Beginning of low (< 5%) *Nothofagus fusca* type values.	160 cm;	Beginning of *Nothofagus fusca* type record, frequencies vary about 5 - 10%. *N. menziesii* record (2 - 3%) begin when *N. fusca* type values first reach their maximum at 130 cm.
Beech forest was probably located in middle/lower foothills locations.		*N. fusca* type values are never high enough to suggest on-site presence or nearby abundance, pollen source must be downslope.		*N. fusca* type values are never high enough to suggest on-site presence and sub-fossil *Podocarpus* logs in Blondin Stream Valley show forest subsequent to the period covered by the diagram not to be beech either.
Composition of beech forest was mountain beech on the upper slopes with patches of silver beech included elsewhere.		No *N. menziesii* pollen except one grain at 0 cm.		*N. menziesii* pollen present. Silver beech in existing forest in the district is in discrete stands rather than being a component of mixed forest.
Decline in upper plains podocarp forest begins, forest being gradually reduced probably by drying climate.			150 cm;	*Podocarpus* values begin steady decline.
Major fire in the Mt. Somers district part-way through the podocarp forest phase.	50 - 25 cm;	Silt, containing fine charcoal fragments up to 30 cm level.		
Dacrydium becomes dominant over *Coprosma* in subalpine scrub early in the forest phase and remains dominant thereafter.	65 cm;	Gradual rise in *Dacrydium bidwillii* type values at 105 cm becoming dominant at about 65 cm and continuing to rise to broad maximum of nearly 60% NAP sum.		
Spread of forest occurs: *Phyllocladus* followed shortly after by podocarp.	85 - 75 cm; 95 - 85 cm;	*Podocarpus* values rise to 30%. *Phyllocladus* frequencies rise to high values (53%).		
Subalpine *Coprosma* scrub gains dominance over floristically diverse subalpine/alpine grassland. A possible *Ecba* component may have been prominent earlier. Beech within pollen dispersal range.	115- 95 cm;	*Coprosma* values become dominant (40%) over grassland species frequencies. 115 - 85 cm; 30% c.f. Scrophulariaceae values at bottom of hole drop sharply and end at 95 cm. 105 - 95 cm; low (5% & 2%) isolated counts of *N. fusca* type pollen.		

Table 12C Lake Sumner district, summary of Raupo Pond site history.

RAUPO POND SUMMARY

^{14}C Date	Depth cm (x10 = age? as far as 1 200 cm)	Reconstruction of Events	Pollen & Sedimentary Evidence
	0	Decreased beech forest (man-caused fires). *Pinus* and *Salix* records of European man.	c. 50% reduction in beech values. *Pinus* & *Salix* pollen.
	80	*Typha* on-site.	Base of root-zone and high *Typha* values.
	100	Expansion of grassland.	Rise in Gramineae pollen.
	250	Beginning of *Typha* swamp.	Macro-remains.
	500-550	Beech forest replaces podocarp on-site; podocarp forest still present.	Steep rise in *Nothofagus fusca* type values to 86%, *Podocarpus* values drop to steady 10%.
	650	Silver beech in the vicinity.	Beginning of low constant values of *N. Menziesii* pollen.
6 990±140 yr B.P.	675		
	700	Possible fire in hills, probable brief expansion of marginal scrub, mountain/red beech in the vicinity.	Silt band with following silt increment in micromud decreasing to 400 cm, brief increase in scrub pollen values, beginning of low values of *N.f.* type pollen.
	1 000	Podocarp forest on-site with *P. dacrydioides* present.	82% *Podocarpus*, beginning of continuous *P. dacrydioides* record.
	1 100	Beginning of replacement of *Phyllocladus* forest by podocarp forest. Expansion of rimu forest in Westland and possibly extra-locally.	Beginning of steep rise in *Podocarpus* and fall in *Phyllocladus*, slight rise in *Dacrydium cupressinum* values.
	1 125	Fire?	2 black soil horizons and black plant fragments (not charcoal) with following silt increment in micromud extending to 900 cm.
	1 150	Podocarp forest in the vicinity, shallow water at coring site but still deepening.	Increasing low values of *Podocarpus*, roots still present in sediment, yellow micromud.
	1 175	Glacial silt deposition finished.	End of silt component.
	1 200	*Phyllocladus* forest on-site.	80% values *Phyllocladus*.
	1 250	*Dacrydium biduillii* becoming prominent probably round pond margin, inorganic siltation nearly finished.	*D. biduillii* type peaking on rising *Phyllocladus* curve, silt increment decreasing.
	1 300	*Phyllocladus* begins to replace *Coprosma* and fern, water begins to deepen.	*Phyllocladus* values beginning to rise, *Coprosma* & monolete falling, sedge band overlain by silt, yellow micromud increasing.
	1 350-1 400	Colonization of moraine, *Coprosma* and fern replace replaces grass *Coriaria* and Cyperaceae, *Phyllocladus* in the vicinity, shallow water and sedge communities.	*Coprosma* and monolete spores values increase as Gramineae *Coriaria* and Cyperaceae fall, low values of *Phyllocladus*, roots in sediment.
		Retreat of late Poulter ice from the site.	>0.5 m blue-grey glacial clay/silt, bottom of hole.

12.2 ARANUIAN FOREST DEVELOPMENT IN MONTANE CANTERBURY

12.2.1 Grassland/Scrubland

The montane areas of Canterbury in the early Aranuian would have been characterized by unstable scree, moraine, and outwash deposits. Soils would generally have been immature to undeveloped on blocky moraines and coarse talus slopes where fine detritus was not able to accumulate. Conditions were probably cold and moist. These factors together with the grassland/scrubland pollen assemblage have prompted the suggestion (Moar, 1971) that this early Aranuian community was subalpine in character and similar to the present day subalpine and alpine vegetation (scrub, grassland, herbfield, and scree vegetation).

The *Coprosma* scrub/grassland phase, the earliest Aranuian vegetation recorded in this study, was widespread if not universal throughout inland Canterbury, and as far as may be judged from the pollen data its basic composition was remarkably uniform (Table 12D). This early grassland/scrubland community is particularly interesting as it forms the first beginnings of the development of woody vegetation in the mountains. There is little information on its earlier history, throughout the late Otiran, and the ecology of similar, existing communities is little known. This hampers our knowledge of this critical transition period in the succession from glacial sedge-rich grassland communities to interglacial forest.

The following account is an attempt to gain more insight into this early Aranuian vegetation phase.

Table 12D. Scrub pollen-types of the early Aranuian grassland/scrubland phase of sites from central montane Canterbury (including Swampy Hill, Otago).

Quagmire Tarn	Windy Tarn	Kettlehole Bog	Mount Horrible	Raupo Pond	Mount Somers	Woolshed Hill	Swampy Hill (Otago)	
✓	✓	✓	✓	✓	✓	✓	✓	*Coprosma*
✓	✓		✓	✓	✓	✓	✓	*Muehlenbeckia*
✓	✓	✓	✓	✓	✓	✓	✓	*Myrsine*
✓	✓			✓	✓	✓		*Leptospermum*
✓	✓		✓		✓			*Coriaria*
✓	✓	✓	✓	✓	✓	✓	✓	Compositae
✓	✓		✓	✓	✓			Chenopodiaceae
	✓			✓	✓		✓	*Plagianthus*
	✓			✓	✓		✓	Umbelliferae
✓	✓	✓	✓	✓	✓	✓	✓	Cyperaceae
✓	✓			✓	✓			Monolete spore
✓	✓	✓	✓	✓	✓	✓		Trilete spore
✓	✓	✓	✓	✓	✓	✓		*Nothofagus fusca* type
✓	✓	✓	✓	✓		✓	✓	*Podocarpus*
✓	✓	✓	✓	✓	✓	✓	✓	*Phyllocladus*
✓	✓		✓	✓		✓		*Dacrydium cupressinum*
			✓		✓	✓		*Dacrydium bidwillii* type
	✓							*Weinmannia*
✓	✓							*Metrosideros*
	✓					✓		*Griselinia*
	✓							*Pseudopanax*
						✓		*Pseudowintera*
	✓					✓		*Libocedrus*

From a knowledge of the present-day subalpine and alpine flora (scrub, grassland, and fell-field species), and the degree of under-representation of some of the constituent taxa in the modern pollen rain, the probable composition of this vegetation may be described in more detail than has previously been attempted. The pollen types present are broad groups, often representing a variety of taxa of different habit and habitat requirements. Many other species will have been present although not represented in the pollen assemblage. Many of the insect pollinated herbs and shrubs of mountain grassland, scree, and rocky bluff, are likely to have been present.

In the grassland, the snowgrasses *Chionochloa macra*, *C. pallens*, *C. rigida*, *C. flavescens*, and *C. rubra*, with probably some smaller tussocks such as *Festuca novae-zelandiae* and *Poa colensoi* would probably have contributed to the Gramineae pollen type. Cyperaceae pollen was probably largely derived from species of *Carex*, *Schoenus*, *Oreobolus* and *Scirpus* that are common components of bog and flush in the Canterbury mountains today. Much of this pollen no doubt derived from on-site mire vegetation, nevertheless it is probable that members of the Cyperaceae were prominent and widespread components of the grassland and outwash plains, and uneven moraine surfaces. Cyperaceae pollen is present in all pollen diagrams covering the early Aranuian in Canterbury and is also characteristic of glacial pollen floras (Moar pers.comm.). The Compositae pollen type includes plants of a wide variety of growth forms. Herb species of Compositae (insect pollinated) were probably common in the grassland. Probable species were rosette

forms such as *Celmisia spectabilis*, common today in the Rakaia mountains, and the cushion and mat formers [e.g., *C. sessiliflora*, various species of *Raoulia*, e.g., *R. subsericea* and *R. grandiflora* - grassland, *R. eximia* (vegetable sheep - rock surfaces), *R. tenuicaulis* - river-bed, and *Cotula* e.g., *C. squalida* - grassland and *C. pyrethrifolia* - screes and moraines]. Umbelliferae would have included various species of *Aciphylla* and *Anisotome* most of whose species have an alpine or sub-alpine distribution. Other insect pollinated alpine herbs that are poorly represented in the pollen rain were almost certainly present, e.g., species of *Ranunculus, Wahlenbergia, Euphrasia, Gentiana.*

Prostrate woody species common in present day high and low altitude grasslands, moraines, and fell-fields, and also scrub, were also probably present, e.g., *Muehlenbeckia axillaris*; members of the Ericaceae (insect pollinated and unrepresented), e.g., *Pernettya macrostigma* and *Gaultheria depressa*; and various prostrate species of *Hebe*. *Blechnum pennamarina*, a common component of moraine, scree, and grassland vegetation, probably contributed to the monolete spore record together with *Polystichum vestitum* which is common on scrub margins. *Pteridium esculentum* may have been the main contributor of trilete spores. The relation between ferns and their spores in the modern pollen rain has not been explored in New Zealand.

The scrub component of this early grassland/scrub community would have included a variety of plant species ranging from creeping, mat-forming plants to divaricate -bushes and large erect shrubs.

Much of the predominant *Coprosma* pollen is almost certainly derived from the small leaved divaricates, eg, *C. parviflora, C. rugosa, C. pseudocuneata, C. ciliata,* all common subalpine scrub species. *Myrsine* pollen will represent *Myrsine divaricata* and probably also the prostrate *M. nummularia* rather than the forest species *M. australis* and *M. salicina*. *Muehlenbeckia* pollen probably derives more from the small leaved prostrate *M. axillaris,* and climber *M. complexa,* than from the large leaved climber *M. australis* that is more common in montane forest than subalpine scrub. Some woody members of the Compositae probably contributed to the pollen sum. Species of *Olearia* (eg, *O. ilicifolia, O. nummularifolia, O. moschata*), *Celmisia* (eg, *C. coriacea*), *Cassinia* (eg, *C. vauvilliersii, C. fulvida*), were all probably present. Unrepresented by pollen but almost certainly prominent would have been various species of *Dracophyllum* (entomophilous) (eg, *D. longifolium, D. uniflorum, D. pronum*) and also various species of *Hebe* (eg, *H. subalpina, H. salicifolia*). *Leptospermum* pollen represents the tall scrub forms *L. scoparium, L. ericoides,* which do not occur in subalpine scrub, but rather on well drained valley-floors (Burrows, pers. comm.). *Coriaria* pollen would have derived from the nitrogen fixing *C. sarmentosa* and perhaps also *C. angustissima* both present day components of subalpine scrub and grassland. The presence of *Plagianthus* pollen and the absence of *Hoheria* pollen is surprising for *Plagianthus betulinus*, the lowland forest species (c.f. *P. divaricatus* - coastal) is much less hardy than *Hoheria glabrata* the montane member of the Malvaceae which is the more probable species to have been present. If *Plagianthus betulinus* was present

scattered in low amounts in the foothills then it would be very unlikely that *Hoheria glabrata* or even *H. lyalli* or *H. angustifolia* were not also present.

Small amounts of tree pollen are recorded from this phase in pollen diagrams both from the study sites and elsewhere in montane Canterbury. These pollen types are mainly forerunners of the later forest phases (*Phyllocladus*, *Podocarpus*, *Nothofagus*) and may have derived either from distant sources of extensive area (e.g., lowland Canterbury plains), or from closer refugia of limited size scattered along the frontal ranges of Canterbury. Contributions from both sources are likely. *Phyllocladus alpinus* was almost certainly present as a component of the early scrub. The occasional *Dacrydium cupressinum* pollen present almost certainly represent the beginnings of the distant Westland rimu forests.

Pollen of *Metrosideros umbellata*, *Weimannia racemosa*, and *Libocedrus bidwillii* (all under-represented trees) is exceptional in being present in this phase of the Windy Tarn and Quagmire Tarn diagrams from Prospect Hill, and also throughout the Lake Henrietta diagram from the Harper tributary of the Rakaia (Moar, 1973a). The very limited distribution of their pollen indicates a local presence of these species. The quantities of pollen present, although very small, are greater than the occasional grain that could be expected to derive from Westland sources. There is an interesting possibility of limited stands of these species, similar perhaps to the present day *Weinmannia/Metrosideros/Libocedrus* montane forests of Westland, existing about the ice margins in the upper Rakaia catchment (if not elsewhere) in the very early Aranuian. This possibility is supported by the present day distribution of these species in Canterbury which although not common, have a

limited presence within the Rakaia and Ashburton watersheds. [*Metrosideros umbellata* occurs at Mt. Peel, and from Mt. Somers to Mt. Hutt along the frontal ranges and in the headwaters of the Rakaia (Mt. Medhurst and Jellicoe Stream) and Mathias Rivers, and is present in the Moa and Kiwi tributaries of the Wilberforce together with *Weinmannia racemosa*. *Metrosideros* is also known from Lake Coleridge and the upper Hurunui River above Lake Sumner. *Libocedrus* is more widespread in Canterbury, with a subalpine distribution]. It is difficult, however, to envisage tree survival in the environs of Prospect Hill during the time of the Lake Heron ice advance - part of the last major advance of the Otira Glaciation in the Rakaia - for ice level then at Prospect Hill was about 1 250 m altitude or higher (Burrows & Russell, 1975) and treeline presumably was depressed below the present natural local altitude of 1 200 - 1 400 m (Molloy & Cox, 1972). Stands of trees would most probably have existed beyond Lake Heron ice in and about the Lake Heron basin, as well as in sheltered sites further east near Mt. Somers.

Of further interest, is the possibility of a relationship existing between these early Aranuian occurrences of *Weinmannia* and *Metrosideros* in the Rakaia, and those in Westland, where the pre-podocarp shrubland phase comprised *Weinmannia* and *Metrosideros*. Dispersal of seed from west to east across the Main Divide was probably as possible then, as it is today, in the violent north-west storms that occur in the alps, but it is likely that this

community survived on both sides of the alps from forests of the last interglacial and that more favourable conditions in Westland allowed greater development there. More early Aranuian data from the foothills and plains in the Rakaia, Rangitata, and Hunters Hills areas, is needed to explore the possibility of a forest containing *Weinmannia* and *Metrosideros* surviving the late Otiran in scattered refugia in moist conditions in the eastern ranges of Canterbury.

The grassland/scrubland phase is now recorded from the Upper Rakaia, Cass and Lake Sumner districts at both low and high altitudes (at c. 600 m - Quagmire Tarn, Windy Tarn, (Upper Rakaia); Kettlehole Bog, Mt. Horrible, (Cass); Raupo Pond (Lake Sumner); and at c. 1 000 m - Mt. Somers; Woolshed Hill (Cass)). The widespread nature of this early Aranuian vegetation of subalpine character suggests that elements of this scrub vegetation occurred scattered throughout all but the axial Canterbury mountains during the late Otiran.

12.2.2 Scrubland

Although the type of scrubland appears to have been similar throughout montane Canterbury, the pattern of the scrubland transition to podocarp forest varies.

Dacrydium bidwillii was briefly dominant at various localities at Cass including the high altitude Woolshed Hill site (c. 1 000 m), and also in the upper Rakaia River at Prospect Hill. This brief dominance is explained by Wardle & Campbell (1976) as a function of frost tolerance.

D. bidwillii was found to possess much greater frost tolerance than the mountain ecotype of *Phyllocladus alpinus* and also mountain beech. However, *D. bidwillii* formed only a minor component of *Phyllocladus* shrubland at two montane sites - Raupo Pond and Mt. Somers. At Raupo Pond, more data are needed to assess the significance of the low *D. bidwillii* values coincident with, rather than preceding, the *Phyllocladus* phase. The absence of the characteristically brief phase of *D. bidwillii* dominance at Mt. Somers (and also at a similar site at Swampy Hill, Dunedin (McIntyre & McKellar, 1970); *contra* Woolshed Hill (Moar, 1971)) and subsequent development during the forest phase until elimination by fire, was at least partly due to the poorly drained nature of both these sites.

Phyllocladus (P. alpinus) shrubland* was a prominent pre-podocarp forest phase at Raupo Pond, Cass, and the Harper tributary of the Rakaia River (Moar, 1973a), but was only briefly present as a pure phase at the Mt. Somers site. At Prospect Hill the pure *Phyllocladus* shrubland phase was not present. There the replacement of *Dacrydium bidwillii* was by a *Phyllocladus/Podocarpus* forest.

The presence, duration, or absence, of the transitional *Phyllocladus* shrubland phase appears to be governed by the amount of lag in the establishment of *Podocarpus* forest.

* see opposite

The continuance in the forest phase, of *Phyllocladus*, appears to depend on the degree of replacement by podocarps, and more particularly, factors of site. Drier and warmer sites would probably have supported a grassland/ *Coprosma* scrub community, while *Dacrydium bidwillii* would probably have occupied the wettest sites in cold positions such as frost hollows and other areas prone to atmospheric inversion effects. Where and when available podocarp species, expanding from small refugia sites, would have invaded those warmer moist sites with established soils. *Phyllocladus* would have remained on the younger immature soils (that would have been widespread at this time) as it does today (Wardle, 1969a).

The role of the *Phyllocladus* shrubland phase, although basically a simple transition to podocarp forest, was complex in detail, and was determined by a complex of variables including distance and position of glacial refuges and the pattern of variation in local climates. *Phyllocladus alpinus*, together with *Dacrydium bidwillii*, is seen to have been widespread through montane Canterbury, and although *D. bidwillii* (of limited pollen dispersal range and an inhabiter of wet sites and therefore most pollen study sites) is not seen necessarily as having been as dominant and as extensive a plant cover as the pollen diagrams would suggest, *Phyllocladus* almost certainly was. *P. alpinus* is thought to have been very widespread in late glacial times surviving the Otiran throughout the Canterbury foothills.

12.2.3 Forest

The replacement of shrubland by podocarp forest would have been achieved by expansion and rapid spread of forest:-

(a) from scattered late-glacial foothills refugia which would have expanded during the shrubland phase, and from further sites which would have been established during the shrubland phase in favoured localities; and

(b) from the lowland plains forest, which would have been steadily expanding westwards towards the alps, during the shrubland phase in the mountains, from more extensive lowland plains forest refugia (e.g., Timaru, Moar, 1973b).

Podocarp forest replaced shrubland with varying degrees of success in montane Canterbury.

At Cass, most sites show that podocarp forest, dominated by *Podocarpus spicatus* (Moar, 1966b; Lintott & Burrows, 1973), appears only to have partially replaced *Phyllocladus* shrubland. Podocarp forest probably was restricted to the warmer parts of valley floors and lower hillsides. Continuing dominance of *Phyllocladus* pollen at Woolshed Hill (c. 1 000 m) (Moar, 1971), shows that the upper forests remained *Phyllocladus* dominant.

To the north and south of the Cass basin *Podocarpus* forest dominated by *P. spicatus* completely replaced *Phyllocladus* shrubland at Raupo Pond and the Sisters Stream tributary of the Hurunui River and almost completely in the Harper tributary of the Rakaia River (Moar, 1973a) and was dominant in both areas for an extended period. In the upper Rakaia River at Prospect Hill, however, there was no period of pure *Phyllocladus* shrubland, and *Dacrydium bidwillii* scrubland was replaced by a mosaic of forest and shrubland. Judging from the pollen evidence *Podocarpus* (mainly *P. hallii*)

and *Phyllocladus* were generally co-dominant forest elements, but local variations in dominance occurred (e.g., *Phyllocladus* at Quagmire Tarn). The scrub present was a mixed *Coprosma* scrub with *Dacrydium bidwillii* present, a community almost certainly surviving from the early scrub/grassland phase.

In the frontal ranges,only two sites show the change from shrubland to podocarp forest. At the high altitude Mt. Somers site podocarp forest is thought to have replaced most of the hillslope *Phyllocladus* except for an upper *Phyllocladus* dominant zone. At a low altitude upper plains site (c. 450 m) at Rubicon Creek (Kowai catchment, near Waimakariri Gorge; Moar, unpub.) podocarp forest completely replaced *Phyllocladus* shrubland there. Dominant *Podocarpus* pollen in the Blondin Stream diagram shows that podocarp forest had replaced shrubland at low altitudes in the Mt. Somers district as well.

The podocarp forests of the frontal ranges foothills and upper plains, were probably similar to the modified remnant forests surviving at Mt. Peel today. Pollen evidence from Blondin Stream, Mt. Somers, and Rubicon Creek (Moar, unpub.), shows that the upper plains forest was *Podocarpus* dominant (*P. spicatus* with minor *P. totara/P. hallii*) with some *Phyllocladus*. *Podocarpus dacrydioides* would have been dominant in wetter places and mixed *Coprosma* scrub in drier places, with *Leptospermum* becoming a more prominent component towards the end of the forest phase at Blondin Stream (if not elsewhere) - an extension perhaps of the mid-plains *Podocarpus/ Leptospermum* mosaic vegetation (Cox & Mead, 1963). Hill forest was probably podocarp on the lower slopes (*P. spicatus*,

P. hallii) with *Phyllocladus* becoming dominant on the upper slopes towards treeline. The role played by *Metrosideros* and *Weinmannia* in these forests is not clear from the pollen evidence. These trees are likely to have formed a significant proportion of hill-country forest. The absence of *Weinmannia* and *Metrosideros* pollen from the Mt. Somers pollen diagram may not be taken as an indication of the non-importance of this forest type in the area: *Weinmannia* and *Metrosideros* montane forest above podocarp forest in Westland has been shown by Moar (1970b) to be severely under-represented in sub-alpine modern pollen samples.

In the reconstruction of the general mountain podocarp forests of Canterbury the following points are of interest.

The occurrence of *Weinmannia* pollen at frequencies as high as those in the Blondin Stream diagram (7%) is not seen in other Canterbury diagrams. In those diagrams *Weinmannia* pollen is often present in trace amounts (e.g., Windy Tarn, Blondin Stream, Lake Henrietta, Woolshed Hill, Lake Hawdon, Mt. Horrible, Raupo Pond) or is otherwise absent.

Weinmannia racemosa, the species represented is an important and widespread forest component of montane and lowland forests in Westland but is rare east of the Main Divide. It is present in coastal Southland and a few

trees occur near Mt. Grey, North Canterbury (Wardle & McCrae, 1966). A little *Weinmannia* together with *Metrosideros* is present in the headwaters of the Wilberforce, Mathias, and Hurunui rivers (Burrows, 1969b) close to the *Weinmannia/Metrosideros* montane forests of Westland just over the Main Divide. *Weinmannia* is also likely to have occurred on the frontal ranges between the Rangitata and Rakaia rivers, where, although unrecorded today, close field associates occur (e.g., *Metrosideros umbellata*, *Libocedrus bidwillii*, *Melicytus lanceolatus*) (C.J. Burrows, pers. comm.).

The known autecology of *W. racemosa* suggests that it requires high, reliable precipitation. Its distribution limits appear today to follow the 150 cm isohyet and Elder reports in Wardle (1966) that it has "exceptionally limited resistance to prolonged drought" under garden conditions. Of further interest from a palynological viewpoint is that *W. racemosa* is insect and bird pollinated (tui, bellbird) and Moar (1970b) has found the tree to be under-represented in the modern pollen rain, as noted below:

Forest Type	*Weinmannia* Tree Frequency	*Weinmannia* Pollen Frequency
Weinmannia	dominant	40%
Metrosideros	common	12%
Dacrydium cupressinum	most common subcanopy tree	2%

The trace presence of *Weinmannia* pollen in the podocarp forest phase of many diagrams from montane Canterbury, and limited pollen dispersal range, suggests that *W. racemosa*

was a widespread component of the podocarp forest of montane Canterbury. *Weinmannia* does not appear to have been a prominent component of the Aranuian lowland podocarp forests of the Canterbury plains. Sub-fossil records do not include *Weinmannia* (Molloy *et al*, 1963; Cox & Mead, 1963; Raeside, 1948; Moar, 1971) and although this may be a function of wood durability, none of the pollen sites on the plains (Timaru, Christchurch, Amberley, Pyramid Valley; Moar, 1971) include *Weinmannia* pollen. The Blondin Stream data (if not a result of chance over-representation),suggests a former abundance of *Weinmannia* in lowland areas in Mt. Somers district. This may mean that *Weinmannia* (and associated species) was common in the forests of the upper plains of central Canterbury and that the *Weinmannia* component in the Canterbury montane forests was of eastern origin.

Plagianthus pollen (of *P. betulinus* the forest tree) is rare in Aranuian diagrams from the South Island. Significant values to date only occur in four diagrams - Windy Tarn, Blondin Stream (this study); Timaru Downs, lowland South Canterbury (Moar, 1971); and Swampy Hill, Otago, (McIntyre & McKellar, 1970). *Plagianthus* pollen is also important in a diagram from Timaru most probably spanning the last interglacial and part of the following Otira glacial (Goh *et al.*, 1978; Moar, 1973b), where its alternating abundance with *Podocarpus* may record colder conditions.

The present day occurrence of *Plagianthus* in Canterbury is limited to a scattered distribution about the 300 m

contour in the foothills at Hunters Hills, Mt. Peel, Mt. Somers, Mt. Hutt, Kowhai Bush, Mt. Oxford, and Mt. Grey. It also occurs in the Mathias headwaters, at Banks Peninsula, Christchurch (Deans Bush), and coastal locations north of the Waiau River (Burrows, 1969b). At Mt. Peel, Allan (1926) describes patches of 15 m high adult trees as being probably "a remnant of a primitive sub-association".

Knowledge of the ecology of *P. betulinus* is limited. *P. betulinus* appears to be drought resistant and to be tolerant of cold (C.J. Burrows, pers.comm.) and in mountain areas in Westland it occurs as a forest margin component on cold valley flats (e.g., Otira and Maruia valleys) and may occur together with *Olearia ilicifolia* and *Libocedrus bidwillii*. It is less hardy than *Hoheria* (*H. glabrata*, mountain ribbonwood) and despite a long pollen record at Windy Tarn is virtually absent from the forest remnants of the upper Rakaia where, instead, *H. glabrata* is common.

The general evidence suggests that *Plagianthus betulinus* was a common component of the podocarp forests of the Canterbury plains and foothills, but not (with the exception of the upper Rakaia Valley and probably also the Lake Heron basin) of the montane forests.

The low values of *Podocarpus dacrydioides* pollen that are generally restricted to the podocarp phase in all diagrams from montane Canterbury represent local occurrences. The distribution of *P. dacrydiodes* in Canterbury today is limited to scattered occurrences along the 300 m

contour, Banks Peninsula, and the Seaward Kaikoura Range (Burrows, 1969b). The pollen evidence shows that *P. dacrydioides* was a widespread component of the valley-bottom forests of montane Canterbury throughout the podocarp forest phase, and that it occurred at least as far up-valley as the 600 m contour.

Dacrydium cupressinum pollen, another ubiquitous pollen type in Aranuian Canterbury diagrams, is generally considered to have derived from the Westland *D. cupressinum* forests as *D. cupressinum* is rare in Canterbury (Franklin, 1968). The higher than usual frequencies of *D. cupressinum* pollen at Raupo Pond suggest, in conjunction with the present very limited distribution of *D. cupressinum* in Canterbury (around the 300 m contour at Oxford, Mt. Grey, north of the Waiau River in the Seaward Kaikoura Range (Burrows, pers.comm.)), that *D. cupressinum* may have been extensive in the mid-Aranuian forests of North Canterbury.

Pollen of *Ascarina* (the small tree *Ascarina lucida*) is another palynomorph that is widely dispersed beyond its present range which for the South Island is coastal Westland (McGlone & Moar, 1977). The *Ascarina* pollen in diagrams from Prospect Hill, Harper River, Cass, and Lake Sumner districts is most likely derived from Westland. *Ascarina lucida* was abundant in the west of the North and South Islands between c. 10 000 and 5 000 yr B.P. but since then it has been severely and progressively

reduced in quantity (McGlone & Moar, 1977). The decrease in *Ascarina* pollen frequencies at Quagmire Tarn accords with these findings but the increased frequencies of *Ascarina* pollen in the latter part of the Raupo Pond diagram does not.

The few *Casuarina* pollen grains identified in the Prospect Hill diagrams are of more distant origin than any of the arboreal pollen types so far discussed, and are considered to have derived from the Australian region (Moar, 1969, 1970b).

A rich understorey of broadleaved, evergreen angiosperm elements would have been common to podocarp forests of most areas. Minor records of these pollen types (*Griselinia*, *Pseudopanax*, *Pseudowintera*, etc.) are generally restricted to the podocarp forest phase in most diagrams (e.g., Quagmire Tarn, Fig. 6.1).

The proportion of scrub present during the podocarp forest phase in the areas under discussion appears to have been greatest in the upper Rakaia where conditions presumably remained relatively harsh. Subalpine scrub of the same general composition was present above the forest at Mt. Somers and its presence was probably fairly universal in the mountains east of the Divide.

From the pollen evidence the broad nature of the podocarp forest is seen to be *Podocarpus spicatus* dominant with lesser amounts of *P. hallii*, *P. totara*, *P. dacrydioides*, and *P. ferrugineus*; with the dominance changing to *P. hallii* in the upper Rakaia and upper Ashburton catchments. It

must be noted that this picture is derived from data from valley bottom sites and probably relates more to valley bottom forest than to montane forest.

P. hallii would have attained dominance in the montane forests. Sub-fossil *P. hallii* logs and charcoal are present throughout montane Canterbury (Molloy, 1969a) and *P. hallii* today has a scattered distribution throughout the montane beech forests of Canterbury.

The amount of the *Phyllocladus* forest and mixed *Coprosma* scrub communities persisting from earlier phases varied locally but generally appeared to increase southward from the Lake Sumner region to the upper Rakaia. *Phyllocladus* was otherwise prominent in the upper montane forests.

As far as is indicated by the limited high altitude pollen data (Woolshed Hill, Mt. Somers, Swampy Hill), *Coprosma* scrub/grassland persisted above tree line. As discussed earlier (12.2.1) this should not necessarily imply uniform composition. Present subalpine scrub composition varies throughout montane Canterbury (e.g., Wardle, 1969a). A high proportion of taxa of these communities are insect pollinated and may not be represented (e.g., *Dracophyllum*) thus wide variations in composition may occur, unrepresented by changes in the pollen data.

Occasional small stands of forest of the *Nothofagus fusca* pollen-type were almost certainly present in the Cass district (Moar, 1971; Lintott & Burrows, 1973) and were probably present in the eastern ranges and foothills of Canterbury.

The complete replacement of podocarp forest by *Nothofagus fusca* type forest occurred at Lake

Sumner, Cass, and the Harper River, but replacement is not demonstrated in the pollen diagrams from Prospect Hill or Mt. Somers districts. The *Podocarpus - Nothofagus* transition is a topic that involves consideration of many factors and is dealt with in a later section (12.5).

Pollen evidence suggests that *Nothofagus fusca* type forest was never widespread at Prospect Hill, was not present on-site at Blondin Stream within the period covered by the diagram (and probably not at all judging from the Gramineae curve), and was not apparently on-site at Mt. Somers. However, the existing beech remnants show beech forest to have been present in the Lake Stream valley; and the present extent and maturity of the beech forest at Mt. Somers, and the early European records showing beech forest to extend some kilometres out onto the plains in the vicinity of Mt. Somers (Vance, 1976), is at variance with the pollen evidence.

Silver beech was locally dominant at Prospect Hill but was apparently not present in the Harper River and Cass districts. In the Lake Sumner district, silver beech was a more prominent forest component near the Main Divide at Springs Bog than further east at Raupo Pond as is the case today. In contrast to the Lake Sumner district, at Mt. Somers silver beech appears never to have been a dominant component of the beech forest, although its pollen record extends back nearly as far as that of *N. fusca* type.

The final event in the forest history of many areas in montane Canterbury was the relatively sudden fire-

induced decline of forest and development of grassland, which has resulted in the present distribution of forest and grassland (e.g., Moar, 1971; Molloy *et al.* 1963; Molloy, 1977). Thus the pollen diagrams from grassland sites (e.g., Lake Hawdon, Kettlehole Bog at Cass (Moar, 1971; Lintott & Burrows, 1973); Raupo Pond at Lake Sumner; and the Prospect Hill and Blondin Stream sites) all display a rise in pollen of grassland species generally at the expense of woody species, whereas the sites within or just above forest do not (e.g., Springs Bog; Woolshed Hill (Moar, 1971)). The role of fire in causing the decline of forest in the study areas is examined in a later section (12.7).

The Aranuian development of forest in montane Canterbury is summarized in Table 12E.

Table 12E Patterns of Aranuian vegetation history, central montane Canterbury.

Note:
- boundaries of vegetation phases are not correlated in time except where indicated by dates.
- 'date' = radiocarbon date
  'date?' = interpolated date
  'date??' = inferred date
- all dates are in yr B.P. (radiocarbon dates are from untreated material).

POLLEN ZONES MOAR (1971)	FIRE EPISODES	PROSPECT HILL	MOUNT SOMERS			CASS BASIN (Moar, 1971)		RUBICON CREEK (Moar, 1973b)	RAUPO POND
			HILL		PLAINS	BASIN FLOOR	HILL		
		c. 750 m	c. 1 270 m		c. 550 m	c. 600 m	c. 1 000 m	c.450 m	c. 580 m
5	European c.120	Fire	Fire		Fire	Fire		No data	Fire
		Tussock grassland Reduced forest	Increased subalpine tussock grassland. Reduced forest and subalpine scrub		Tussock grassland. Very little forest	Tussock grassland. Reduced forest		Tussock grassland. Very little forest	Increased grassland. Some reduction of forest
4	Polynesian c.500-500	Fire	Fire		Fire	Fire		No data	Fire
		Reduced *P.hallii/ Phyllocladus* forest. Expansion of local silver beech forest c. 2 000	Mountain beech replacing montane podocarp forest beginning probably after fire	*D.bidwillii* dominant over *Coprosma* in subalpine mixed scrub	Declining montane podocarp forest	Mountain beech montane forest	Mountain beech montane forest	Mountain beech/ podocarp mixed montane forest	Montane mixed beech forest probably mountain and red beech with silver beech to the west
	Pre-settlement	Subalpine *Podocarp-*							
		Fire c. 3 500?							
		us hall/Phyllo							
		Fire c. 6 000	Fire c. 6 000??			c. 6-7 000?		c. 6-7 000??	c. 5 500?
3		*cladus alpinus* mosaic forest and subalpine *Coprosma* mixed scrub	Podocarp montane forest	*Phyllocladus* upper montane forest. *Coprosma* dominant *D. bidwillii* in subalpine scrub	- - - - - - -	Montane podocarp forest	Montane podocarp forest / Subalpine *Phyllocladus* scrub	Montane podocarp forest	Montane podocarp forest
2		c. 10 000	Very brief phase of subalpine *Phyllocladus alpinus* low forest/tall scrub		NO DATA	Subalpine *Phyllocladus alpinus* forest/scrub	Subalpine *Phyllocladus alpinus* forest/scrub	Subalpine *Phyllocladus alpinus* forest/scrub	Subalpine *Podocarpus alpinus* forest/scrub. Some *Dacrydium bidwillii* (prob. local)
		Very brief *Dacrydium bidwillii* scrub phase				Very brief *Dacrydium bidwillii* scrub	Very brief *Dacrydium bidwillii* scrub	Very brief *Dacrydium bidwillii* scrub	
1		Alpine grassland/ subalpine *Coprosma* dominant mixed scrub c. 12 000	Alpine grassland/ subalpine *Coprosma* dominant mixed scrub			Alpine grassland/ subalpine *Coprosma* dominant mixed scrub	Alpine grassland/ subalpine *Coprosma* dominant mixed scrub	Sparse alpine grassland with *Coprosma* mixed scrub present	Alpine grassland/ subalpine *Coprosma* dominant mixed scrub.

Limited pre-Aranuian evidence in montane Canterbury indicates that late-Otiran vegetation comprised sparse open grassland/herbfield, sedge prominent, scrub rare to absent, no forest.

12.3 THE ARANUIAN CLIMATE HISTORY OF MONTANE CANTERBURY

12.3.1 Introduction

A stable altitudinal sequence of vegetation encompassing the main communities represented in the pollen diagrams, may be taken as representing a sequence determined by decreasing warmth with increase in altitude, and may be used as a basis of interpretation of pollen evidence, on uniformitarian principles. A generalized downwards altitudinal vegetation sequence in the Southern Alps is from alpine fell-field/herb-field to alpine grassland, to a generally well-defined scrub belt in which species of *Coprosma*, and *Phyllocladus alpinus* are often prominent components, to beech forest (where present) to finally podocarp forest.

In post-glacial pollen sequences from montane Canterbury, the above sequence is broadly followed (i.e., grassland-scrubland-forest), but there are three major anomalies:- the reversed positions of *Nothofagus fusca* type and *Podocarpus* in the pollen sequence compared with the altitudinal vegetation sequence; the absence of *Dacrydium bidwillii* from the modern altitudinal vegetation sequence in contrast to the post-glacial pollen sequence; and the absence of the modern equivalent of the distinctive and widespread Aranuian grassland/*Coprosma* dominant scrub phase in the present-day subalpine zone. The implications of the first two anomalies noted become evident in the body of this discussion of climate history. With regard to the third anomaly, the apparent dominance of *Coprosma* in the early Aranuian scrub is likely to be an artefact arising from gross over-representation of *Coprosma* species (wind pollinated) in the pollen assemblage, combined with severe under-representation of other important components, many of which in existing subalpine scrub are

insect pollinated (e.g., *Dracophyllum, Olearia, Hebe, Senecio*). However, the early Aranuian pollen assemblages do not show *Phyllocladus alpinus* to be a prominent scrub component in the grassland/scrub phase, as it is today in the subalpine scrub of Canterbury. This is probably due to a combination of too cold a climate and too limited a survival of *Phyllocladus* in the Canterbury mountains during the Otiran.

Inferences of climate made from pollen data are hampered by two main factors:-

i) the broadness of most of the pollen groupings which usually include taxa of diverse ecologies and habit,

ii) the broad ecological amplitude of the major taxa involved.

Thus *Coprosma, Nothofagus fusca* type, *Podocarpus*, and Compositae pollen groups all include species which together encompass a broad spectrum of environmental parameters, and which singly (e.g., *Nothofagus solandri* var. *cliffortioides, Podocarpus hallii*) may be possessed of just as wide an ecological range as the combined ranges of all the species in the pollen group to which they belong.

Further difficulties are imposed by a paucity of detailed knowledge of the autecology of many species and their synecological requirements under competition with other members of the various communities of which they are part. Edaphic factors have scarcely been considered. Good indicator species are generally rare in number, their ecologies as yet inadequately studied, their pollen inadequately represented, and their community status minor. The limited knowledge of how important reactions such as the competitive ability of communities (and hence migration of same) are governed by environmental conditions, restricts the interpretation of such changes that have occurred in the past. Further indications of climate may be

erosional and depositional features (e.g., glacial moraines, palaeosols, and ancient lake strandlines).

Consequent upon these various impediments are the very loose and subjective terms of reference used with respect to climate interpretations. Climatic interpretations are relative and are limited basically to such terms as harsh, cold, cool, warm; and dry, moist, and wet.

Moar (1971, 1973b) has reviewed the development of the reconstruction of Aranuian climate for the South Island from available pollen data.

The early Aranuian scrubland/grassland period is generally accepted as being subalpine in character, indicative of cool, moist conditions (e.g., Moar, 1971; Lintott & Burrows, 1973). The late Aranuian elimination of forest at least in Canterbury is accepted as being largely due to fire (e.g., Moar, 1971; Molloy, 1977). Climatic interpretation, from the Aranuian development of forest vegetation : scrubland-podocarp-beech, however, is not unified, due to a complex of factors involved. Present views are:-

- that the sequence of forest types is a response to a sustained rise in temperature which began with the final retreat of Otiran ice about 14 000 yrs ago (Walker, 1966; Moar, 1966a, 197
- that the late Otiran, sedge-dominant, grassland pollen assemblages from montane Canterbury (e.g., Harris in Suggage, 1965; Moar, 1973b; Russell unpub.) suggest cold, bleak conditions at times of the last Otiran glacial maximum (e.g., Moar, 1973b)
- that the early Aranuian grassland/scrubland vegetation was subalpine in character and indicates cool, moist conditions (Moar, 1971); cold conditions (Lintott & Burrows, 1973)
- that the early, post-glacial *Dacrydium bidwillii* phase was characterized not only by low mean temperatures

but also by very low minimum temperatures, and that the transition from *D. bidwillii* to *Phyllocladus* implies a decrease in frost intensity and frequency (Wardle & Campbell, 1976)

- that the development of podocarp forest at about 10 000 yr B.P. may be attributed to a general warming occurring at about this time (Moar, 1966a; Walker, 1966; Lintott & Burrows, 1973)

- that conditions for podocarp forest involved more uniformly wet and milder climate than now exists in the areas of former abundance (e.g., Cranwell & von Post, 1936)

- that no major climatic change occurred during the forest period but that a drift towards less equable conditions occurred which may have initiated, but did not directly control, the replacement of podocarp forest in critical areas (Moar, 1971)

- that the replacement of *Podocarpus* by *Nothofagus* represents a fundamental environmental change and cannot be accounted for by migration lag from a distant source area (Lintott & Burrows, 1973)

- that "the change from podocarp to *Nothofagus* must imply a response to climate change during the forest period, although the threshold may have been crossed in different regions at different times" (Moar & Lintott, 1977)

- that the incidence of frost and drought increased over about the last 5 000 years causing the decline in abundance of *Ascarina lucida* in the west of both North and South Islands (McGlone & Moar, 1977)

- that climates are still fluctuating and that complete equilibrium between vegetation and climate is not yet achieved (and indeed will probably never be) (Holloway, 1954; Wardle, 1973; Burrows & Greenland, 1979).

12.3.2 Climate during the Grassland/Scrubland phase.

The early grassland/shrubland was subalpine in character and appears to have been common to both high and low altitudes (e.g., Mt. Somers, Quagmire Tarn) although the composition may have varied within the broad pollen groupings.

The prominent Cyperaceae and fern pollen and spore frequencies are not reliable indicators of moistness of climate. These taxa almost certainly formed an important on-site component at mire and tarn sites throughout the Aranuian. Most of the pollen therefore was probably derived from these on-site communities as it is today in modern pollen samples. However, in view of the Cyperaceae dominant pollen floras characteristic of the late Otiran in the Southern Alps (e.g., Handisides Stream, Waiau Valley; Station Creek, Buller Valley; Reid Stream, Springs Junction;(Harris in Suggate, 1965); Rubicon Creek, Waimakariri foothills;(Moar, 1973b)), Cyperaceae, in the absence of forest vegetation was probably widespread in the scrub/grassland in sites of impeded drainage and may, at least, indicate the absence of summer drought.

The prominence of mixed *Coprosma* scrub shows that conditions were milder than those in the late Otiran when woody vegetation was apparently rare.

Although the data are limited, and the *Coprosma* pollen group a diverse one, it appears that the ratio of *Myrsine* to *Coprosma* in the mixed scrub is related to wetness of climate. Diagrams from sites in areas of high precipitation show *Myrsine/Coprosma* pollen percentage ratios of 1:1 (Nan's Kettle, Maria's Mire, N. Westland; Moar, 1971) or higher (2.5:1 Gillespies Beach Road, S. Westland; Moar, 1973a; 2:1 Enderby Island, Auckland Island, Fleming *et al* 1976). Ratio values in Canterbury diagrams vary between 1:2 (Windy Tarn; Pyramid Valley, Moar, 1970a) to virtually no *Myrsine* pollen present (Kettlehole Bog, Lintott & Burrows, 1973; Quagmire Tarn; Raupo Pond), indicating drier conditions. It is not at present possible to speculate beyond this gross distinction.

The evidence from the Rakaia catchment and Mt. Somers suggesting the presence of limited stands of *Metrosideros/ Weinmannia/Libocedrus* forest near the ice margins, suggests that local climate may have already been approaching montane zone conditions at this time within the Canterbury mountains (c.f., proposed foothills refugia locations further east).

Conditions during the early grassland/scrubland phase in montane Canterbury were probably largely moist (but not wet, as *Myrsine* is not prominent) and cool to cold (milder than the late Otiran/early Aranuian when woody vegetation was scarce).

12.3.3 Climate during the Scrubland phase

The significance of the brief phase of *Dacrydium bidwillii* type pollen dominance in the Gramineae/*Coprosma* - *D. bidwillii* - *Phyllocladus* - *Podocarpus* - *Nothofagus* - Gramineae sequence, present in almost all Aranuian pollen diagrams from montane Canterbury, has long been difficult to assess for it is not usually a component of a present day altitudinal sequence. Wardle & Campbell (1976) have investigated the ecology of *D. bidwillii* and found that it is much more frost-hardy than the alpine ecotype of *Phyllocladus alpinus*, and that its general absence from the alpine timberline is related to the scarcity at high altitudes of the overmature, poorly drained soils upon which it is competitive. They suggest that persistent ice and snow fields allowed deep atmospheric inversion effects, causing severe frost conditions to persist in intermontane basins where *D. bidwillii* may have formed extensive communities on overmature soils beyond the ice limits. Examples of the divaricate *Coprosma* species most likely to have been present in the earlier scrub/grassland phase were not included in the frosthardiness tests but presumably, (being the earliest woody Aranuian vegetation) the species then present were hardier than either *D. bidwillii* or *Phyllocladus*. On this assumption then, *D. bidwillii* fits into the sequence *Coprosma* scrub/grassland - *D. bidwillii* - *Phyllocladus* and indicates a decreasing intensity of frosts and a progressive warming.

The pollen diagrams from Prospect Hill show that the brief period when conditions were favourable to *D. bidwillii* development did not occur there until about 10 000 yr B.P. shortly after the Lake Stream ice advance, more than

2 000 years after the retreat of ice from Prospect Hill of the last major advance of the Rakaia glacier which left Lake Heron moraines on Prospect Hill. Other evidence that conditions were ameliorating at about this time is provided by the decrease in extent of ice in the Rakaia Valley. The Lake Stream glacial advance which occurred between about 11 500 and 10 000 years ago (Burrows and Russell, 1975) was less than half the length of the present Lake Heron/Acheron 3 advance, though more than twice as long as the glaciers of later advances in Aranuian time near the head of the Rakaia Valley (Burrows and Russell, 1975). Similar advances occurred elsewhere in the Southern Alps (McGregor, 1967; Burrows, 1973; Wardle, 1973). The climate fluctuations causing these (and later) advances were apparently of insufficient magnitude to affect the pollen curves.

In the Lake Sumner district at Raupo Pond, the low *D. bidwillii* values coincident with (rather than preceding the *Phyllocladus* phase, are probably a result of conditions having been milder at this site than those that prevailed near the Main Divide and closer to the centre of glaciation in the Cass and Lake Heron/upper Rakaia districts.

The widespread transition in Canterbury from *Dacrydium bidwillii* to *Phyllocladus* scrub/forest, or codominance in *Podocarpus hallii/Phyllocladus* forest in the Rakaia, is taken as evidence of conditions continuing to ameliorate. Temperatures were still cool with probably lighter and fewer frosts. It is difficult to judge wetness of climate during these pre-forest phases; evapotranspiration stresses would have been low in the still cool environment. Conditions were perhaps wetter than before with climate probably being similar to that experienced by the subalpine zone of the

wetter mountains east of the Main Divide in the South Island, (eg, upper Rakaia subalpine zone, annual average rainfall >2 m) where *Phyllocladus alpinus* vegetation today attains its greatest prominence (but note *Phyllocladus alpinus* and *Dacrydium bidwilli* in low rainfall areas in Central Otago (Bliss and Mark, 1974).

12.3.4 Climate during the Forest phase

Assessment of climate conditions during the forest period is complicated by considerations of the different rates of migration of *Nothofagus* and *Podocarpus* species (Preest, 1963); their differing (but often overlapping) inter- and intra-generic ecological requirements (eg, Wardle, 1970); their varying (and as yet little known) inter-competitive abilities under different climate regimes (eg, Wardle, 1970); and their probable differences in source location and size in the late Otiran. Evidence from available diagrams suggest that climate varied temporally and spatially throughout montane Canterbury during the forest phase.

Conditions in the Canterbury mountains in the earlier part of the forest period may have been generally similar to those now prevailing in central lowland Westland or Stewart Island where podocarp forest is extensive today. Mean temperatures in montane Canterbury may not have been much different from present day values, but extremes, of low temperature

especially, were probably less.

There are several indications that climate changed during the forest phase.

- The significance of the incoming of beech pollen must be assessed with caution. The usual assumption is that dominant beech pollen in a diagram indicates a drier climate with lower, less reliable rainfall, and cooler conditions (with perhaps more frosts), than that required by podocarp forest. This is based on general field evidence and knowledge of the ecological tolerances of the communities involved: the extensive beech forests of Marlborough, Canterbury, and inland Otago occur in comparatively low rainfall, montane areas. Studies of the relations of beech and podocarp communities in Fiordland forests especially, have shown beech (particularly mountain beech) to possess "a wider range of tolerance for conditions of low rainfall, high altitude, low soil fertility, and poor soil drainage than most other New Zealand tree species" (Wardle, 1970, p.528). But that "as soils improve and the climate becomes more conducive to forest growth, mountain beech becomes progressively less important in stand composition" and "fails to compete successfully with the broadleaved hardwood species, the podocarp species and even the other beech species" (Wardle, 1974, p.21). However due to the uncertainties in the interpretation of beech migration (Section 12.5) the transition from podocarp to beech pollen dominance in a diagram does not necessarily indicate a contemporaneous change to the above climate conditions favouring beech. Such conditions may have existed in places for some time prior to the incoming of beech.

As far as present pollen evidence and the availability and accuracy of radiocarbon dates allow, the spread of beech occurred in the following locations in montane Canterbury at about 6 000 years B.P., (see Fig. 12.1)[194] : the intermontane Lake Sumner district; the intermontane Cass district; the upper Waimakariri catchment near the Main Divide at Bealey River; and in the eastern Waimakariri foothills at Rubicon Creek. Elsewhere in eastern South Island beech spread at about 5 - 6 000 years ago at Pyramid Valley, lowland North Canterbury (Moar, 1970a); and at Swampy Hill, Dunedin, coastal Otago, *Dacrydium cupressinum* began to spread in the podocarp forests there very close to 6 000 years ago (shortly before 5 870 ± 90 yr B.P. NZ770; McIntyre & McKellar, 1970) and was accompanied by an expansion of minor elements of silver and mountain beech. The spread of beech forest at Mt. Somers half-way through zone MS3 is likely to have occurred at a similar time. In the upper Rakaia, conditions cannot have been sufficiently improved for beech spread to have occurred. Nevertheless the beginning of a sustained decline in podocarp forest there (Q.T.) and the assumption of significant beech pollen values (Q.T. and W.T.) is likely to have occurred at around 6 000 years ago.

It would appear from these dates from montane, intermontane, foothills, plains, and coastal locations that a significant change in regional climate occurred about 6 000 years ago. Other pollen data do not disagree (e.g., *Pseudowintera*, *Ascarina*, see following). The effects of the change are likely to have varied throughout eastern South Island, but in montane Canterbury the change is

likely to have resulted in a change from mild, equable conditions with higher rainfall than at present, to less equable and probably cooler conditions, with less rainfall, similar to the existing climate.

- There is little indication from the dominant pollen profiles of the podocarp forest phase that significant changes in climate occurred between about 6 000 and 10 000 yr B.P. *Podocarpus* and *Phyllocladus* pollen profiles do not exhibit any marked changes that are consistently evident in pollen diagrams from central montane Canterbury. The changes that do occur are not major and may be accounted for by differences in site.

- The Blondin Stream diagram, from a much drier area than the upper Rakaia, may be valuable in indicating increasing dryness towards the end of the podocarp forest phase. *Weinmannia* frequencies cease before the long decline in *Podocarpus* begins and the mid-zonal drop in *Plagianthus* values occurs. Increases in Gramineae and *Leptospermum* begin at about the same time, and the accompanying development of dense roots in the sediments demonstrates a lowering of water level.

- The former presence of forest containing *Podocarpus spicatus*, *P. ferrugineus* and *P. dacrydioides*, far upvalley in the Canterbury mountains where conditions are now generally adverse to their survival, indicates that conditions were more equable earlier in the forest phase.

- McGlone & Moar (1977) have attributed the post-5 000 yr B.P. decline of *Ascarina* in the west coast of both North and South Islands to increasing frequencies of drought and frost. The general absence of *Ascarina* pollen in

the latter part of the Quagmire Tarn forest phase supports McGlone & Moar's data, but the initial absence and later presence of *Ascarina* pollen in the forest phase at Raupo Pond does not.

- *Pseudowintera* pollen, where present, is without exception more frequent early in the forest phase and less frequent or absent in the later part of the forest phase of diagrams from montane Canterbury. *Pseudowintera* pollen shows a progressive decline through the forest phase of Quagmire Tarn; is absent from the latter half of the forest phase of Windy Tarn and Kettlehole Bog; is more frequent in the earlier half of the forest phase of Lake Henrietta and Mt. Horrible diagrams; and although sparse, is more frequent in the earlier part of the forest phase of the Woolshed Hill and Lake Hawdon diagrams. This is seen as further evidence of a climate becoming drier and perhaps cooler. *Pseudowintera colorata* today is a common component of Westland rain forest and is not common in montane Canterbury. It is present at Mt. Algidus, and upper Rangitata, and is scattered along the foothills, but is rare in inland basins in Canterbury. (C.J. Burrows, pers.comm.), and is regarded as an indicator of mild moist climate (Lintott & Burrows, 1973).

- At Raupo Pond, the very low silver beech representation may show that the present limits of silver beech in the montane forests of the Hurunui catchment (primarily controlled by the eastward fall-off in precipitation) have never in the past extended eastward to Raupo Pond. This would suggest that conditions have not been much wetter than today in the Lake Sumner district during the beech forest phase

there (c. 5-6 000 yr B.P. - P.D.).

In addition to the evidence suggesting that climate changed throughout the forest phase, there are also indications that climate varied locally.

There is little indication of local variation during the beech forest phase due to the problems mentioned earlier, but there are indications of local variation in climate in the podocarp forest phase of diagrams from montane sites in Canterbury.

Whereas differences from site to site in the proportions of pollen of the different forest types (e.g. podocarp and beech) may be attributed to differences in the composition of late Otiran sources of the local forest, and differences in the pollen spectra of individual sites will result from differences in site environments; broad differences in the composition of an individual forest type, evident from a number of sites in a district should reflect differences in regional climate.

- Conditions were wet enough and mild enough for the establishment of *Podocarpus spicatus*-dominant forest containing *P. ferrugineus* and *P. dacrydioides* in the Lake Sumner, Cass, Harper River, and Mt. Somers districts. At Prospect Hill on the other hand, the predominance of *P. hallii* among the podocarps, the co-dominant status of *Phyllocladus*, the persistence of apparently considerable amounts of mixed *Coprosma* scrub, and the very late spread of beech, all suggests a harsher or colder climate. However, the presence throughout the forest phase of the Prospect Hill diagrams of pollen of *Podocarpus dacrydioides*

and *Pseudowintera*, both indicators of mild moist conditions (Lintott & Burrows, 1973) and also the predominance there of *Plagianthus* pollen over that of the hardier *Hoheria* in the mixed scrub pollen spectra must be noted. Edaphic factors may have been responsible for the prominence of scrub, but the Prospect Hill sites bear a similar relationship to moraines of the late Otiran as do other sites at Cass and Sisters Stream.

In summary, with few exceptions, the pollen evidence shows that a change initiated at about 6 000 yr B.P. caused a deterioration from the early peak in mild moist climate. Conditions became generally drier and cooler towards the present during the forest phase, with probably an increasing incidence of drought and frost. Climate also varied locally with conditions being probably harsher in the upper Rakaia district than in other montane areas further north. There is no record in the pollen diagrams of recent change in climate as proposed by Holloway (1954) and other workers. This event would most likely have been too minor in scale to be recorded, and in any case would have been overshadowed in the pollen record by the effects of fire, which are evident in most Canterbury diagrams as an abrupt change from forest to grassland.

The effects of fire preclude further interpretation of climate from the pollen evidence of the grassland phase. Field evidence of regeneration in existing beech forests in montane Canterbury suggests that a forest climate still prevails.

12.3.5 Summary

The overall picture is presented of an initial improvement in Aranuian climate at 10 000 yr B.P. to mild moist conditions followed by a deterioration at 6 000 yr B.P. which has persisted to the present day. Table 12F summarizes the evidence and deductions which lead to the following reconstruction.

Cold wet conditions with heavy frosts, similar to today's alpine and subalpine climates gave way at 10 000 yr B.P. to a milder more equable climate. Conditions during this early forest period were probably similar to the present central lowland Westland or Stewart Island climate, being milder and more equable than before with less extremes of frost, and milder or more equable than at present in montane Canterbury with more consistent and greater rainfall. These conditions deteriorated at about 6 000 yr B.P. to conditions similar to present day in montane Canterbury, becoming drier and probably colder and less equable. The decline in conditions took effect probably as much by increases in climate extremes, causing increased frequency, duration, and intensity of drought and frost, thus affecting seedling mortality, as by mean decline in values of climate parameters. Such a breakdown in weather conditions could be caused by long-term variation in one of the major determinants of the climate of the south temperate regions as for example, a breakdown in stability of the path of the circumpolar jet stream (e.g., Ponte, 1976).

This reconstruction is in general accord with a growing body of data in the southern hemisphere (e.g. Burrows, 1979),

Table 12F Aranuian climate history of montane Canterbury.

Table 12F Aranuian climate history of montane Canterbury

Date, yr B.P.	Reconstruction of Climate	Evidence
	Post c. 6 000; conditions never much wetter than present-day.	Limits of silver beech in the Lake Sumner district appear never in the past to have extended to Raupo Pond.
	Post c. 6 000; climate becoming drier.	Steady decline in *Podocarpus* pollen frequencies beginning at mid-zone QT 2.
	? Post c. 6 000; climate becoming drier.	? Post c. 6 000; at Blondin Stream *Weinmannia* pollen frequencies cease, followed by a long decline in *Podocarpus* with increasing Gramineae and *Leptospermum*.
c. 6 000	Regional climate change at c. 6 000 yr B.P. to less equable conditions becoming drier and probably cooler approaching present-day conditions with increasing incidence of drought and frost. Conditions in the Rakaia were harsher than in catchments further north.	Spread of beech in montane, intermontane, foothills, plains and coastal locations at c. 6 000 yr B.P. Decline in *Pseudowintera* in montane Canterbury halfway through the forest phase. (Post-5 000 yr B.P. *Asoarina* decline in western South and North Islands.)
	Climate has become mild, moist and equable, similar in nature to present-day upper lowland/ lower montane zone climate of central Westland.	Podocarp forest dominant with *P. spicatus*, *P. ferruginaus*, and *P. daorydioides* present in areas where these species cannot now survive. *Pseudowintera* generally present throughout montane Canterbury. (*Asoarina* common in lowland Westland forests.)
	Little significant change in climate from c. 10 000 - c. 6 000 yr B.P.	No marked consistent changes in frequencies of pollen dominants.
c. 10 000	Climate continuing to ameliorate, still subalpine in nature but with fewer and lighter frosts. Climate in montane Canterbury was probably similar to that of present-day upper montane/lower subalpine zone in the upper Rakaia.	Change in dominance from *Daorydium bidwillii* to *Phyllocladus alpinus* shrubland/forest or *P. alpinus/Podocarpus hallii* forest in the Rakaia Valley.
	Beginning of progressive warming, decreasing intensity of frosts.	Change in scrub dominance from *Coprosma* spp. to *Daorydium bidwillii*. Lake Stream glacial advance (c. 11 000) < half the magnitude of previous advance in Rakaia Valley.
	Climate similar to present-day subalpine climate exists throughout montane Canterbury.	Grassland/shrubland of subalpine character; no montane forest; some trees of present-day mid-subalpine zone upper altitudinal limit near ice.
	Cool to cold, milder than late-Otiran.	Woody vegetation present, c.f., late-Otiran grassland.
	Moist but not wet.	*Myrsine* not prominent scrub component.
c. 12 000	No summer drought.	Cyperaceae is a prominent and widespread grassland component.

and in the south-west Pacific area in particular (New Guinea, south-eastern Australia, and Tasmania, e.g., Hope & Peterson, 1976; Bowler *et al.*, 1976, Dodson, 1974, a,b; McPhail, 1979) which demonstrates similar climatic trends for the last 10 000 years.

12.4 THE TIMING OF FOREST EXPANSION IN MONTANE CANTERBURY.

The 10 000 ± 150 yr B.P.(N.Z.1653) date for the transition from *Coprosma* scrubland/grassland to *Phyllocladus/Podocarpus* forest at Prospect Hill may be put forward as a tentative date for the beginnings of extensive forest in montane Canterbury. This fits with other dates from central and southern South Island which show that the expansion of early Aranuian forest there was approximately synchronous and did not occur before about 10 000 years ago (Table 12G).

Table 12G Dates for forest expansion in the South Island

Transition of Pollen Dominance	Years B.P.		Location	
Scrub-*Phyllocladus/Podocarpus*	NZ1653	10 000±150	Quagmire Tarn, Rakaia, Canterbury	This study
Weinmannia-Dacrydium cupressinum	NZ829	9 230±150	Nan's Kettle, Bell Hill, N. Westland	Moar, 1971
Shrub-*Podocarpus*	NZ302	9 820±155	Crooked Mary Ck., N. Westland	Moar, 1971
Shrub-*Podocarpus*	NZ772	9 850±120	Swampy Hill, Otago	McIntyre + McKellar, 197(
Shrub-*Podocarpus*	R4015/1	c.9 900±100	Timaru, S. Canterbury	Moar, 1973(b)

This contrasts with the North Island and northern South Island where glaciation was not as severe (and the climate milder) as in central and southern South Island, and where podocarp forest had expanded widely by c.12 000 yr B.P. or soon after (McGlone & Topping, 1973, 1977; N.T. Moar, pers. comm., 1978; Dodson, 1978).

12.5 THE SPREAD OF BEECH FOREST IN THE CANTERBURY ALPS

12.5.1 Introduction

Discussion of the spread of the Canterbury beech forests must involve the broader questions posed by the pattern of beech forest distribution in the South Island (Fig.2.8)[28].

The absence of beech forest from the middle of the South Island has long been attributed to the severity of the Otira glaciation there (e.g., Cockayne, 1926). The apparent anomaly presented by the presence in this region of podocarp rainforest, rather than the less mesophytic beech forest, has been explained by the rapid post-glacial migration of podocarps (due to bird distributed seed) as compared to beech (Preest, 1963). Identification of, and the relative importance of, the factors influencing the expansion of the vegetation surviving the Otiran has since been a source of controversy. Obviously the improving post-glacial climate allowed extension of plant communities into previously uninhabitable areas, but such factors as the location, extent, and composition of Otiran refuges; soil type; the different ecological tolerances of the various species involved; the competition between these species and their differing rates of dispersal - all factors influencing migration rates - must also be considered. Furthermore, it is important to realise that the present day distribution of beech represents the cumulative effect of the stadials and interstadials of the Otira glaciation and the last interglacial as well, and does not just represent a simplistic readjustment beginning with the end of the

final stadial of the Otiran. The status of the present beech boundaries therefore, and the relative importance of the factors influencing the post-glacial spread of beech in the central South Island are still in question. Present theories explaining vegetation history in the South Island variously emphasize that post-glacial spread and the present extent of beech was controlled by the rate of amelioration of post-glacial climate or by an inherently slow rate of migration for beech from northern and southern refugia. Both schools of thought recognize that spread of beech may be hindered by competition with prior established vegetation (e.g., podocarp forest).

The migration ecology of beech, a clear knowledge of which is necessary for the understanding and reconstruction of beech and podocarp forest history, and past environments, has not been investigated in depth. Differences of opinion exist concerning the commonly accepted slow rate of migration for beech species. The seed (of relatively small size and low density, and possessing small wings) appears to be suitable for dispersal by wind, but regeneration arising from wind-borne seed does not normally extend much beyond 200 m from either isolated trees (Wardle, 1970), or from the margins of a parent stand (Preest, 1963). Spread is by growth of seedlings under the peripheral edge of the forest or stand canopy, but it is recognized that stream transport of seed may lead to relatively fast riparian extension (e.g., Wardle, 1970). More recently it has been shown that dispersal and establishment may occur over long distances. Burrows

(1977) has reported instances in the Cass district of beech seedlings in scrub up to 6 km from source, and describes small beech stands in the Otira and Taramakau valleys in Westland which are "several to many kilometres distant from more extensive forest". Stands similar to these occur elsewhere in North Westland (see following). Thus there is opportunity for beech seed to be transported long distances at times, but this appears rarely to result in establishment.

Migration may be limited more by requirements for seedling establishment and growth away from the seed source (i.e., nursery conditions such as provided by mature *Leptospermum* scrub (Wardle, 1970)), than by the dispersal range of seed which has not yet been directly measured or estimated. Important influencing factors are likely to be the absence in new territory of the beech root mycorrhiza fungi, essential to good growth, and the probably underestimated effect and frequency of storm strength winds which gust to 160+ k.p.h. in the Southern Alps.

Data from North Westland (Moar, 1971) show that the spread of beech there was not synchronous. The evidence has been interpreted as demonstrating a southward migration of beech from a source in Nelson occurring over some 5 000 years, and a recent diagram from Nelson showing beech to have been present there as an increasingly dominant component of beech/podocarp forest for the last 10 500 yr B.P. (Dodson, 1978) is in accordance with this view. This has been taken (Moar, 1971) as evidence of a slow migration of beech southward from Nelson into the faster migrating podocarp forest, already established following deglaciation, with migration being controlled by the

limited range of beech dissemination, rather than by a progressively improving post-glacial climate in central Westland.

Later work has shown that the situation in Westland is likely to be more complex. Beech has been shown to have been present in the middle of the "beech gap" in Westland near Hokitika in a late Otiran podocarp-beech-grassland pollen sequence (Moar & Suggage, 1973). Last interglacial sites from central and southern near-coastal locations within the present "beech gap" (Dickson, 1972; Nathan & Moar, 1975) also show beech to be prominent in forest to grassland pollen sequences. June (1977) has reported the presence of *Nothofagus truncata* (a component of North Westland beech forests) south of the "beech gap" at Jackson's Bay, demonstrating survival of beech there during glacial times and indicating a former distribution range extending south through the present podocarp forests of central Westland. Current work on the distribution of beech species in North Westland (S.R. June pers. comm.) shows that beech has almost certainly survived the last glaciation south of the present beech/podocarp interface as well as in other localities there. In North Westland many stands of varying size lie scattered in podocarp forest beyond the beech front. Most of these stands may be reasonably explained as being products of chance long distance dispersal but others may not. One of the largest stands contains all four species of the North Westland beech forest (*Nothofagus solandri* var. *cliffortioides*, *N. fusca*, *N. menziesii*, and *N. truncata*), lies some 13.5 km distant from the beech front, and must almost certainly represent a site in which beech

survived through the last glacial.

Superimposed upon these large scale historical considerations in Westland are the present day, small scale, species migration patterns existing within the beech front, which show that migration of beech species is not occurring in sequences consistent with what is at present known of the ecology of the various species concerned (S.R. June, pers.comm.). The present day beech species patterns at the beech front in North Westland thus do not appear to represent a response that is consistent with control by climate change alone. Other factors, such as the detailed distribution of forest and forest tree species in the late Otiran, are likely to be involved.

Data from Canterbury show that the situation on the eastern side of the alps in North Canterbury is as complex as that in Westland, and that it is further complicated by the widespread reduction of forest by fire and exploitation by man.

The southern limit of present day beech forest in Canterbury is very irregular and fragmented (Fig. 2.11)[32]. Much of this fragmentation is due to fire, but some outliers (e.g., at Banks Peninsula) must represent refugia positions of beech survival through the last glacial. Radiocarbon dates from Lake Sumner, Bealey River, Rubicon Creek, Harper River, and the upper Rakaia Valley (Fig. 12.1) document the establishment of extensive beech forest in montane Canterbury and allow comparison with the data of Moar, (1971, 1973b). Further evidence from Templeton and Christchurch shows beech to have been present in the

Figure 12.1 The timing of the rise to dominance of *Nothofagus fusca* type pollen, in pollen diagrams from sites in Nelson, Canterbury, and North Westland. (Dates are in approximate years B.P. and are based on radiocarbon dates listed in Table 12G over-page).

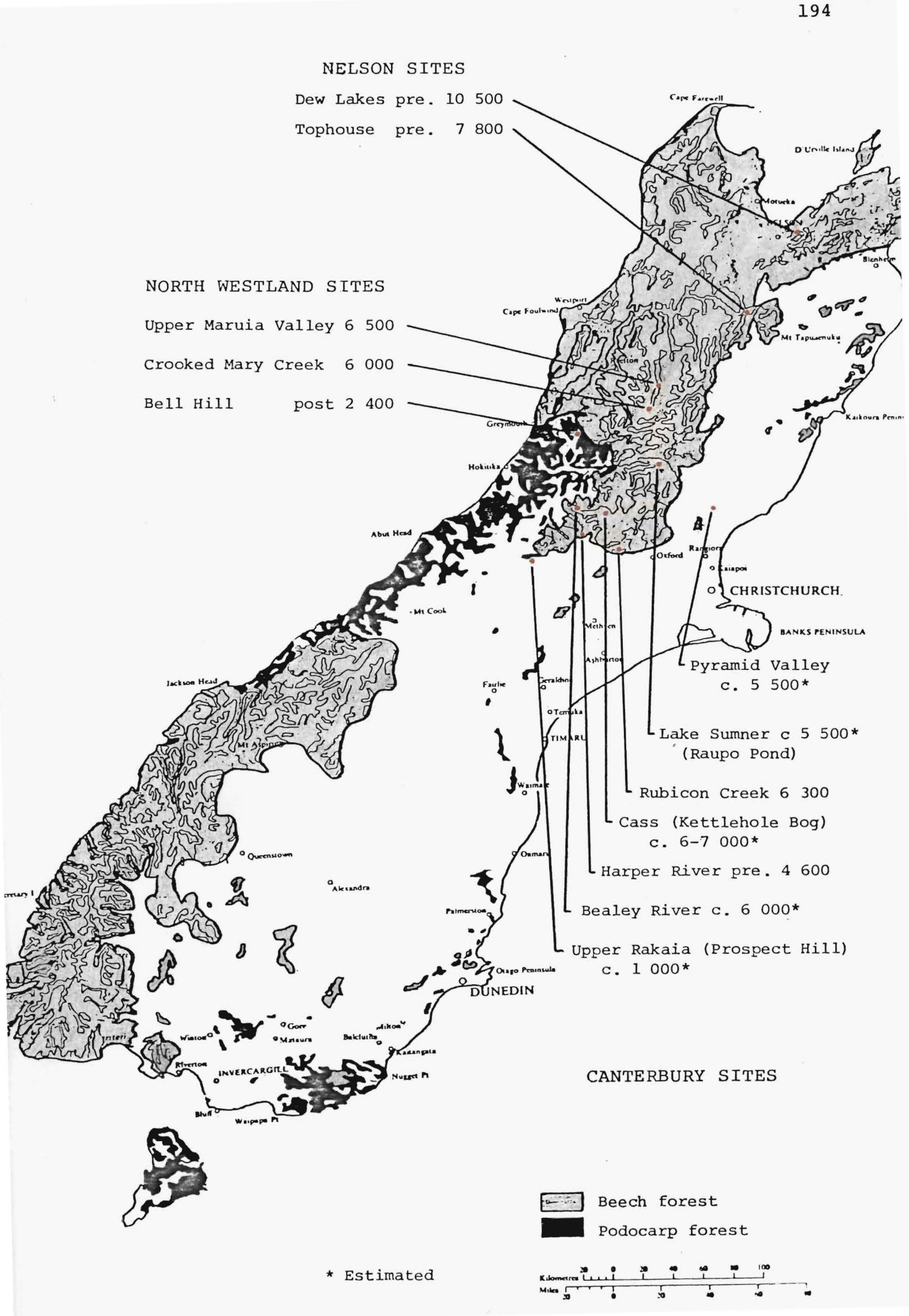
NELSON SITES
Dew Lakes pre. 10 500
Tophouse pre. 7 800
NORTH WESTLAND SITES
Upper Maruia Valley 6 500
Crooked Mary Creek 6 000
Bell Hill post 2 400
Cape Farewell
D'Urville Island
Motueka
NELSON
Blenheim
Westport
Cape Foulwind
Mt Tapuaenuku
Greymouth
Kaikoura Penin
Hokitika
Abut Head
Oxford
Rangiora
Kaiapoi
CHRISTCHURCH
Mt Cook
Methven
BANKS PENINSULA
Ashburton
Pyramid Valley
c. 5 500*
Jackson Head
Fairlie
Geraldine
Temuka
TIMARU
Lake Sumner c 5 500*
(Raupo Pond)
Mt Aspiring
Waimate
Rubicon Creek 6 300
Cass (Kettlehole Bog)
c. 6-7 000*
Queenstown
Oamaru
Alexandra
Harper River pre. 4 600
Palmerston
Bealey River c. 6 000*
Upper Rakaia (Prospect Hill)
c. 1 000*
Otago Peninsula
DUNEDIN
Gore
Mataura
Balclutha
Kaitangata
Riverton
INVERCARGILL
Nugget Pt
Bluff
Waipapa Pt
CANTERBURY SITES
Beech forest
Podocarp forest
* Estimated
Kilometres
Miles

TABLE 12H Radiocarbon dates from which is derived the timing of the post-glacial spread of beech forest in the northern South Island.

Dew Lakes,	*N. fusca* type pollen prominent and increasing	10 430±240	GX 4729 (Dodson, 1978)
Sloping Bog, Tophouse	*N. fusca* type pollen dominant before this date	7 820±95	NZ 1077 (Moar, 1971)
Ure's Mire, Upper Maruia Valley	Rise to dominance of *N. fusca* type pollen	6 530±85	NZ 1078 (Moar, 1971)
Crooked Mary Creek, upper Grey Valley	Wood sample, not in place dating rise in *N. fusca* type pollen	6 070±75	NZ 741 (Moar, 1971)
	Shortly before rise to dominance of *N. fusca* type pollen	6 560±100	NZ 301 (Moar, 1971)
Nan's Kettle, Bell Hill, Lake Brunner	Low (< 15%) *N. fusca* type pollen frequencies at a site 7 km from present day extensive beech forest	2 390±35	NZ 830 (Moar, 1971)
Pyramid Valley	Soon after rise to dominance of *N. fusca* type pollen	4 280±62	- (Gregg, 1966)
Raupo Pond, Sisters Stream, Lake Sumner	Late in podocarp forest phase	6 990±140	NZ 1822 (this study)
Rubicon Creek	Beech spreading into podocarp forest phase	6 330±115	NZ 1390 (Moar, 1973b)
Kettlehole Bog, Cass	Late podocarp forest	8 250±145	NZ 1076 (Moar, 1971)
Hamilton Creek, Harper River	Dates not associated with a pollen diagram, subfossil wood samples establishing a minimal age for mountain beech forest	4 620±80	NZ 72 (Molloy & Cox, 1972)
		4 550±80	NZ 73 (Molloy & Cox, 1972)
Upper Waimakariri River	*N. fusca* type pollen dominant	4 830±90	NZ 1594 (Burrows unpub.)
Bealey River	*N. fusca* type pollen dominant	5 180±90	NZ 1905 (Burrows unpub.)
Bealey River	*Phyllocladus* pollen dominant	7 600±110	NZ 1904 (Burrows unpub.)
Quagmire Tarn, Prospect Hill, upper Rakaia River	Rise to dominance of *N. menziesii* pollen	1 975±90	NZ 1654 (this study)

lower plains podocarp forests over 6 500 years ago (Cox & Mead, 1963; Moar, 1971). A major difference in forest composition exists between the forests of the beech fronts in North Westland and Canterbury. The predominantly red, silver, mountain, (and hard beech (*N. truncata*) in N. Westland) mixed beech forest of the northern South Island extends about the same distance southwest along both sides of the alps (to approximately the Arnold and Taramakau Rivers in Westland, and the Hurunui and Cox Rivers in Canterbury). But whereas in North Westland this mixed beech forest forms the southern limit; in North Canterbury, mountain beech forest extends beyond the mixed beech forests of the Waiau, Hurunui, and Cox, to the southern boundary in the Rakaia, Ashburton, and Rangitata catchments. Small midslope pockets of red beech, and occasional silver beech, are present in this mountain beech forest in the Mingha-Hawdon-Andrews region of the Waimakariri Valley (red beech for at least 500 yrs (Molloy, 1977)), and (red beech only) at Mt. Oxford and Mt. Grey.

Of further relevance to considerations of beech migration are the isolated stands of silver beech beyond southern limits of beech forest in Canterbury. With the exception of those silver beech stands in the tributaries of the Waimakariri River, which are most probably derived from the mixed beech forests of the Hurunui and Cox catchments; the small isolated stands of silver beech in Canterbury are located near the central South Island limits of the northern and southern beech forests of the eastern alps (Rakaia catchment, Mt. Somers; Lake Pukaki, Mt. Cook), and in foothills locations within the 'beech gap'. These lie outside the former limits of the Otira ice (Suggate, 1965) and may represent former midslope refuge sites inhabited during the last glaciation (Fig. 2.11)[32].

Also pertinent is the accumulating evidence of pre-

Aranuian beech forest in Canterbury. It has been seen (section 12.2) that several pollen diagrams from montane Canterbury imply scattered sources of beech pollen in the foothills in the early Aranuian. There is also evidence of beech forests in montane Canterbury from deposits of the last interglacial. A site at Joyces Stream in the foothills of the Waimakariri catchment demonstrates a podocarp-beech-grassland/scrubland sequence and records the transition from interglacial to glacial (Otiran) (Moar & Gage, 1973).

12.5.2 Discussion

The radiocarbon dates from Prospect Hill and Sisters Stream in conjunction with dates from the Waimakariri Valley (Fig. 12.1) help establish the timing of the spread of beech forest in montane Canterbury.

The interpolated Sisters Stream date of c.5 500 yr B.P. is much older than the date of beech spread at Bell Hill (post-2 400 yr B.P.) directly across the Main Divide but is consistent with the distance of the site from the southern limit of present day beech forest in Canterbury.

The dates from the Waimakariri district (Rubicon Ck. 6 330 yr B.P., Cass c.7 000 yr B.P., Bealey River c.6 000 yr B.P.), suggest that beech began to spread there at about the same time or even before expansion occurred in the Lake Sumner district at Sisters Stream. This, together with the difference in forest types between the two areas and the presence of early Aranuian beech pollen in some Cass diagrams, suggests that the Waimakariri forests originated from local sources inhabited during the late Otiran, probably on the foothill ranges near the Waimakariri gorge, from which beech spread west into the mountains.

The pre 4 620±80 yr B.P. age of the beech forests of the Harper River accords with their proposed origin from the Waimakariri forests (Molloy & Cox, 1972).

The indications of mountain beech expansion at Prospect Hill about 1 000 years ago is consistent with the site's location just outside the main limits of beech forest. The origin of the mountain beech forest in the upper Rakaia River near Prospect Hill is uncertain. The late establishment may reflect spread from the Waimakariri source or from smaller more isolated sources in the headwaters of the north and south branches of the Ashburton River where silver beech appears to have survived the late Otira glaciation. Both source areas are probably involved. The evidence of spread of beech in the Mt. Somers district is difficult to interpret. Expansion was limited mainly to hillslopes, and probably occurred around 6 000 years ago from local hillslope refugia. The forests in the catchments of the Rakaia, Wilberforce, Mathias, Ashburton, and Rangitata are only remnants of a complex mosaic destroyed by fire. Detailed ecological investigations of the structure and dynamics of the remaining stands of forests; elucidation of the former (pre-Polynesian fire) extent and distribution of beech and podocarp forest; and dated pollen diagrams from more sites, are required before an authoritative palaeo-reconstructio can be made. To a casual inspection of an undisturbed example of beech-podocarp interface at Moa Stream (Wilberforce Valley) the boundary appears to have been static for a considerable time (at least 500 - 1 000 yrs, i.e., lifespan of a podocarp). There are no relict stands or trees on either side of the boundary (denoting invasion one way or the other), and no significant penetration of the boundary by regeneration occurs on either side (G.H. Stewart, pers.comm.). The inference

of this, together with the Prospect Hill pollen evidence of only a very recent beech history, is that the beech boundary in montane Canterbury is, and has for the last thousand years or so, been controlled by stringent interspecific competition between dominants of the two forest types under the overall influence of climate.

For montane Canterbury, the evidence that I have been able to assemble does not permit a clear and consistent reconstruction of beech history to be formulated. A simple picture of invasion from the north by a wave of beech forest cannot be sustained. Expansion of large, mixed, northern sources undoubtedly did occur, but the podocarp forests of the Waimakariri appear to have been replaced by beech from a different monospecific source, into which the northern mixed beech has infiltrated via low saddles into the northernmost tributaries. The complex mosaics of beech and other forest types, the remains of which exist in the Rakaia and Rangitata watersheds, were probably typical of the earlier beech-podocarp transition period in other areas, where in the present beech forests, rare isolated relict stands or single trees from these earlier forests yet survive. The presence of beech in the *Podocarpus spicatus* plains forests at 6 495 yr B.P. (Cox & Mead, 1963), the relict type of distribution of silver beech in central Canterbury, and the presence of beech on Banks Peninsula all fit in with this picture of a mosaic pattern of change in forest types.

The distribution of beech in the South Island in the

late Otiran - early Aranuian is not seen to relate simply to massive refugia in the north and south, consequent on the disruption of the Otira glaciation, as implied by Cockayne (1926); Wardle (1963); and Burrows (1965). Instead, a scattered distribution of small refuges is envisaged, whose frequency (density), and individual size, increased on a gradient away from the centre of glaciation as increasingly favourable conditions away from the harsh environment of the main glacial areas allowed the presence of more and larger refuges.

The spread of beech in the Aranuian is therefore seen as having been governed by the speed of coalescence of stands (spreading from refugia) which would have been dependent on the inherent rate of beech migration from a refuge, competition with other species outside a refuge, and upon refugia density and size. The degree to which the extra-refugia species were favoured by the local climate obtaining would influence the competitive ability of beech, and thus its migration rate: for example, a local climate with high rainfall and warm conditions would inhibit the spread of beech in the face of competition from podocarp forest species. The overall controlling factor of beech spread would have been climate, the local expression of which would have varied as to location.

The spread of beech in the Aranuian at any location in response to climate change must therefore be controlled by:-

i) the presence of refugia

ii) the position of the location on a general climatic gradient away from the harsh centre of glaciation

iii) the magnitude of change with respect to the climatic factors limiting beech spread

iv) modifying factors (e.g. local climate, local vegetation, topographical and other migration barriers).

To simplify, a location may be thought of as occurring in any of three broad sectors of the climatic gradient:-

A) the least favourable sector - the centre of glaciation where conditions are inimical to beech survival and where beech refugia are either absent or rare

B) the intermediate sector - where conditions allow the presence of scattered beech refugia

C) the most favourable sector - most distant from the centre of glaciation, where beech is present, having survived the Otiran glaciation there in substantial quantities.

Using this model, the c. 6 000 yr B.P. climate change is seen as having been of sufficient magnitude to allow conditions favouring spread of beech to occur in the intermediate sector (B), but not in the least favourable sector (A), while the change would have had little effect on the most favourable sector (C) apart from an expansion of the already extensive beech refugia surviving the Otiran there.

This explanation fits the data from Canterbury where the Upper Rakaia and Cass/Lake Sumner districts correspond respectively with sectors A and B. The explanation also holds for North Westland where the Bell Hill and Crooked Mary Creek/Upper Maruia Valley districts correspond respectively with sectors A and B and where the spread of

beech forest in the intermediate sector (Crooked Mary Creek/Upper Maruia Valley) is also dated at about 6 000 yr B.P. Nelson (Tophouse, Dew Lakes) corresponds with sector C.

12.6 THE HISTORY AND ORIGIN OF THE ISOLATED SILVER BEECH STANDS AT LAKE STREAM AND MT. SOMERS, CANTERBURY.

Nothofagus menziesii pollen values of up to 60% at Quagmire Tarn, and low values at Windy Tarn, demonstrate the presence of local silver beech forest at Prospect Hill during the last 2 000 years. A long extra-local history is indicated by the presence of a *N. menziesii* leaf at an extimated 5 500 years (QT 420 cm) at Quagmire Tarn and the trace amount of *N. menziesii* pollen there, extending back an estimated 8 000 years, nearly as far back as the post-glacial spread of forest in the area at 10 000 yr B.P.. This pollen evidence, and the increasing occurrence of silver beech in the present-day forest remnants on the eastern side of Lake Stream Valley towards Lake Heron (Fig. 4.1)[52], suggests that silver beech survived the late Otiran somewhere in the Lake Heron basin.

The pollen diagrams from Mt. Somers and Blondin Stream do not offer convincing evidence of late-glacial silver beech refugia in the Mt. Somers area. In the diagram from Mt. Somers, the absence of *N. menziesii* pollen is most probably due to site factors. The low but continuous *N. menziesii* record at Blondin Stream is similar to that at Windy Tarn and, together with the *Nothofagus fusca* type curve, records only the expansion of these forest types late in the podocarp forest phase.

Although there is no direct pollen evidence for silver beech occurring locally during the late Otiran in the

diagrams from Prospect Hill or Mt. Somers areas, this is more likely a reflection of the probable small size and isolated nature of the proposed refuges, combined with under-representation, than anything else. The hypothesis that silver beech survived the late Otiran in these areas is not disproven. It remains the simplest hypothesis, considering the unlikeliness of long distance seed dispersal and establishment of the disjunct small stands of silver beech in central and southern Canterbury.

12.7 THE FIRE HISTORY OF THE STUDY AREAS

There is widespread evidence of past fires in both lowland and inland areas of the eastern South Island (Fig. 12.2). Most of the evidence consists of charcoals in both surface and buried soils both within and beyond present forest boundaries. Other evidence is drawn from buried forest soils (podsols), windthrow dimples, and subfossil remains, which indicate formerly more extensive areas of forest. Radiocarbon dating of the charcoals has shown a history of both natural and man caused fires throughout Aranuian time. In montane Canterbury charcoal is extensive along the foothills and frontal ranges and has been found within many mountain valleys, ranging from valley bottom to above treeline.

Table 12I broadly summarizes the fire history of Canterbury.

There is good evidence in the intermontane district of Prospect Hill in the form of charcoal fragments, fossil pollen, and buried soils, for several fires. These events are likely to have been part of more major Canterbury episodes proposed by Molloy (1977).

i) There is evidence of recent European fires in the upper Rakaia Valley.

ii) The fire at the change from forest to grassland pollen dominance at about 860 radiocarbon years ago is within the range of dates for the Polynesian fire episode (see page 47 for critical information on the reliability of radiocarbon dates from buried charcoal, wood, and peat material).

iii) The proposed fire at an estimated 3 500 years ago accompanying a rise in Gramineae pollen values and the beginning

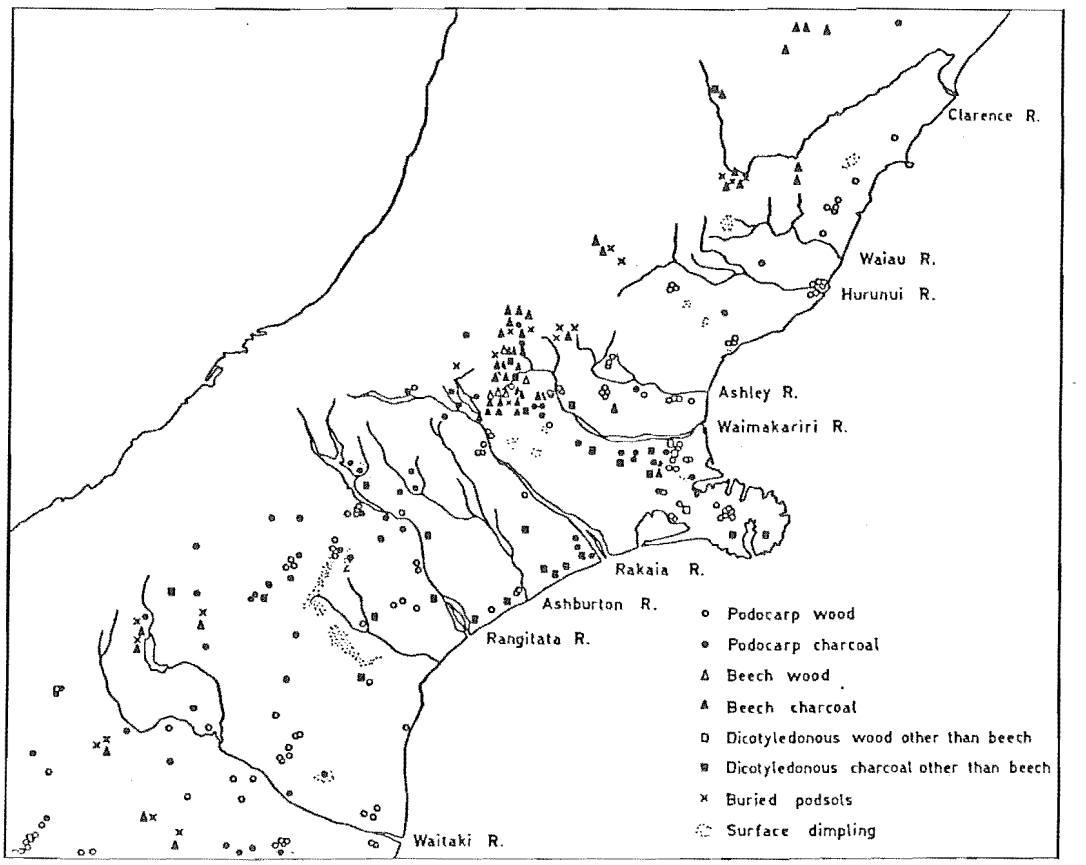

Figure 12.2 Distribution of subfossil forest remains in Canterbury (from Molloy, 1969a).

Table 12I Major fire episodes in Canterbury

Sources:
Cox & Mead, (1963); Grant-Taylor & Rafter, (1971); Moar, (1973b); Molloy, (1964); Molloy, (1977); Molloy, *et al.* (1963).

PERIODS	FIRE EPISODES
European 1850 A.D. - present (100 yr B.P.- P.D.)	Repeated large fires in the 1860's with many smaller fires up to the present day. "Burning off" land clearing/ pasture improvement, accidental sawmill and other fires.
Polynesian c. 1000 A.D. - 1850 A.D. (c. 1 000 yr B.P. - 100 yr B.P.)	c. 800 - 500 years ago. Catastrophic fire episode deforesting much of the eastern South Island after the beginning of Polynesian settlement about 1 000 A.D. Generally thought to be caused by deliberate and accidental fires of the Polynesians.
Pre-settlement pre- c. 1000 A.D. (pre- c. 1 000 yr B.P.)	2 000 - 3 500 years ago. Several radiocarbon dates for charcoals are grouped within this period. 5 000 - 6 500 years ago. A large cluster of radiocarbon dates for charcoals within this time range suggest a major fire episode. Pre-Aranuian. Evidence of fire has been found in sediments of late Pleistocene age. (Molloy, 1964, p.175; Moar, 1973b, p.189).

of *Nothofagus menziesii* pollen records, may fall within the 2 000 - 3 500 yr B.P. fire period. The possibility that the silver beech forest expansion was triggered or aided by fire is particularly interesting in view of the later destruction of beech forest by fire.

iv) The fire dated at 5 830 radiocarbon years ago in about the middle of the podocarp forest phase, falls within the 5 000 - 6 500 yr B.P. fire period.

In the foothills district of Mt. Somers there is evidence of:-

i) One or two less major fires above treeline occurring near the end of the podocarp forest phase, and

ii) an upper plains fire at the change from lowland podocarp forest to grassland. These are all likely to be part of the Polynesian fire period.

iii) A major fire in the middle of the podocarp forest phase shortly before the beginning of *Nothofagus fusca* type pollen records is likely to fall into the 5 000 - 6 500 yr B.P. fire period.

In the Lake Sumner district:-

i) the reduction of beech forest at Sisters Stream was almost certainly caused by Polynesian fires.

ii) European fires occurred in the Sisters Valley but not in the upper Hurunui Valley.

The above evidence included in Table 12E[169] adds to the knowledge of the timing and magnitude of past fire episodes in Canterbury.

The additional evidence shows that the Polynesian fires that caused widespread destruction of forest over the Canterbury plains and eastern South Island about 500 - 600

years ago also extended into the frontal ranges and all the major river catchments between and including the Hurunui in the north and the Rakaia/Ashburton in the south.

The incidence of fire in the Aranuian assumes additional importance in view of the proposed climate change at c. 6 000 yr B.P. The following is a possible interpretation.

The proposed climate change at c. 6 000 yr B.P. promoted drier conditions which allowed the major fire episode at 5 - 6 500 yr B.P. (and subsequent fires) to occur in Canterbury. This fire episode may have aided the expansion of beech, which was occurring in response to the climate change, by destruction of forest (podocarp and beech) allowing beech to establish preferentially in the changed climatic conditions. In the wetter conditions of the upper Rakaia this same fire episode had little effect, but conditions were apparently drier later, when the c. 3 500 yr B.P. fire at Prospect Hill had more effect, causing increased grassland and being followed, subsequently, by the spread of silver beech there.

The later, widespread destruction of beech forest by Polynesian fires contrasts with the possibility of this c. 6 000 yr B.P. fire episode assisting the expansion of beech. The Polynesian fire episode however is thought to differ from the earlier ones by almost certainly consisting of repeated major fires which occurred at relatively short intervals, progressively reducing beech forest and allowing beech little chance of recovery. Climatic conditions affecting beech regeneration probably differed also.

The Polynesian fire episode comes at a time when the

podocarp forest pollen values of the Prospect Hill diagrams, and more especially the Blondin Stream diagram, are showing that the podocarp forests there were declining in response to a presumed drying in climate. The Polynesian fires are therefore seen as the coup de grâce in a long established history of decline of montane podocarp forest in the Upper Rakaia - Lake Heron - Mt. Somers region.

CHAPTER 13

CONCLUSION

The study has shown the progression of the changes in Aranuian vegetation to be complex and only partly explains them. The difficulties inherent in the interpretation of pollen data are evident. It may also be seen that the understanding of the development of Aranuian vegetation in central montane Canterbury is hampered by the limited data available, the nature and geographic origin of these data, and by the present state of knowledge of the ecology of the plant communities involved.

The most pressing need in Canterbury, as pointed up by this study, is for a thorough investigation to be made of the vegetation history of the foothills of the Canterbury Alps, including the Hunters Hills of South Canterbury and Mts. Thomas and Grey of North Canterbury. Not only do the pollen data suggest that these have been late Otiran survival areas, but remnant stands and representative species of former podocarp forest occur today in South Canterbury and (mixed with beech forests) in North Canterbury. In addition to findings of general interest, there should be elucidated some of the problems concerning the spread of beech (e.g. a definitive date for when conditions began to favour beech) and also the causes of the scattered distribution of isolated silver beech stands in Canterbury.

The finer definition of Aranuian climate trends and the relationship of fire to vegetation changes can only come with the obtaining of further radiocarbon dated data

from more sites. This will allow the progressive extinctions and expansions of communities to be traced in areas sensitive to changes in climate - the peripheral areas of present local climate districts, treelines and other boundaries of present plant communities and species distributions (e.g. silver beech) that are undisturbed by recent fire. This information will be able to be used more accurately when there is gained a more intimate knowledge of the ecological requirements, the migration ecology, and pollen representativity of the communities and species involved.

To complete the picture for Canterbury, sites should also be sought in coastal locations (Banks Peninsula in particular) in order to confirm the premise that extensive coastal refugia existed on the extended land area of Otiran time, which served as source areas for the reafforestation of the plains.

The discovery of sites of late Otiran refugia in Canterbury and elucidation of their Otiran and Aranuian history will be of prime interest.

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I would finally like to state that the general presentation, structure, and text, and the ideas expressed therein, have not been influenced unduly by the thinking of any one person, and have been developed as well as I am able to, from the available data.

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APPENDIX I

SITE STRATIGRAPHIES

QUAGMIRE TARN

Depth (cm)	Sediment
0-20	*Sphagnum* peat, moderately humified; abundant rootlets and rhizomes; dark brown.
20-120	Zone of dense fibrous roots, humified *Sphagnum* and water; no sample obtainable; brown.
120-150	Brown macromud with abundant rootlets; fine charcoal fragments present around 120 cm; silver beech leaves present 120-300 cm; *Potamogeton* seeds abundant throughout.
150-340	Yellow brown macromud; rootlets becoming sparse with increasing depth; silver beech leaves present to 300 cm; *Potamogeton* seeds are abundant to 270 cm and decrease in frequency thereafter to become sparse at 340 cm; *Phyllocladus alpinus* cladodes present 300-470 cm; fine charcoal fragments 300-360 cm.
340-690	Grey brown sandy silty macromud which becomes more compact with depth; a few fine rootlets present to 420 cm; *Dacrydium bidwillii* leaves common 340-690 cm; increased sand fraction and increased *Dacrydium bidwillii* leaves 550-600 cm; *Phyllocladus alpinus* cladodes present to 470 cm and further cladodes were recorded from 520, 540, 570, 640, and 660 cm; *Potamogeton* seeds present in low frequencies to 510 cm.

Depth (cm)	Sediment
690-708	Transition to grey sandy silt.
708-732	Grey sandy silt with sharp lower boundary.
732-745	Grey brown sandy silty macromud as before; abundant rootlets.
745-50	Transition to blue grey sandy silt.
750-760	Grey blue silty clay.

WINDY TARN

Depth (cm)	Sediment
0-1	Dense fibrous black peat.
1-26	Yellow brown slightly humified *Sphagnum* peat.
26-30	Grey brown moderately humified *Sphagnum* peat, abundant roots and rhizomes throughout, some silt.
30-40	Grey silty *Sphagnum* peat, abundant roots.
40-60	Yellow brown moderately humified *Sphagnum* peat.
60-240	Soft brown poorly humified *Sphagnum* peat becoming more humified,watery, and darker brown in colour with depth down to about 230 cm where samples were too fluid to be retrieved. Roots and rhizomes abundant in the top 30 cm and less frequent with depth.
240-259	The above peat becomes less watery.
259-560	Grey brown macromud with silt: 330-360 cm grey macromud with high silt increment; 392-396 cm light grey fine sand/silt; 450-560 cm fine yellowish rootlets, moderate concentration, even distribution.
560-600	Transition to slightly brown grey muddy silt, rootlets less frequent.
600-788	Brownish grey muddy silt grading into: dark grey silty clay at 690 cm, brownish light grey silty clay at 730 cm, and blue grey clay at about 784 cm. A 0.5 cm band of blue-grey silty clay occurs at 750 cm.
788-810	Brownish light grey silty clay as before, sharp upper contact and grading down into blue grey silty clay at bottom of hole.

MT. SOMERS

Depth (cm)	Sediment
0-5	Loosely compacted yellow brown macromud with fine charcoal fragments.
5-15	Grey silt, fine charcoal increases down to 15 cm, a thin band of orange *Sphagnum* occurs at 12 cm.
15-25	Orange brown *Sphagnum*, no charcoal.
25-50	Dark grey silt, fine charcoal becoming more frequent with depth.
50-67	Dark red brown macromud, dark red leaf bases of *Schoenus pauciflorus* at 55 cm complete with root zone extending down to 67 cm.
67-70	Yellow brown macromud.
70-90	Dark brown macromud (slightly fibrous) grading to yellow brown in colour as fibres become less frequent with depth.
90-120	Becoming increasingly fibrous and darker in colour with depth changing through grey brown (silt present) to orange brown to black brown. Last 20 cm is virtually solid fibrous peat.
120	Bottom of hole, stony.

BLONDIN STREAM

Depth (cm)	Sediment
0-80	Light brown fluid sediment; dense roots from 40 cm; no sample obtainable.
80-200	Macromud, colour change 80-90 cm light brown to dark brown; dense fibrous roots to 120 cm; 120-140 cm roots become sparse; 130-140 cm colour change to brown; 140-160 cm occasional rootlet; 160-200 no roots.
200	Stony bottom.

RAUPO POND

Depth (cm)	Sediment
0-60	Roots of *Typha orientalis*, and water.
60-105	Light brown decomposing *Typha* leaves.
105-120	Transitional to micromud.
120-706	Grey brown micromud at top which grades down through a mottled yellow/black stage to light yellow micromud at 150 cm. The micromud extends down to a 0.5 cm grey brown silt band at 706 cm becoming darker and more compact with depth and more cheese-like in consistency and fracture and with silt content increasing with depth. *Typha* leaves do not occur below 250 cm. At 547 cm a 7 cm silt rich zone lies above a 0.5 cm blue grey silt band.
706-900	Pure, dense, light yellow micromud with no apparent inorganic fraction. A 2 cm grey silt-rich band occurs at 815 cm.
900-907	4 cm band of light grey silt; upper contact sharp, lower contact gradational over 3 cm.
907-1 120	Light yellow micromud (as above) whose silt content and grey brown colour increases with depth to a very dark grey micromud. 5 cm bands of black mottling occur at 920 cm and 940 cm.
1 120	Sharp contact with banded unit below.

Depth (cm)	Sediment
1 120-1 136	Complex of fine banding including two intact and closely spaced soil horizons. The root zones of both horizons are established in yellow dark grey silty mud and are surmounted by black silt, rich in small black pliable unidentified plant fragments, no charcoal fragments were found.
1 136-1 400	Light yellow grey micromud grades to silty clay at bottom of hole. Silt content and grey colour increases with depth. Blue clay bands and grey silt bands are present throughout. A gradation through grey argillaceous silt occurs at about 1 300 cm to blue grey clay at about 1 380 cm. Rootlets vary in abundance as indicated on the pollen diagram and are unrelated to any soil horizon. A 10 cm band of blue grey clay occurs at 1 310- 1 320 cm and is surrounded by 8 cm of dense small grass-like leaves. No root zone visible.

SPRINGS BOG

Depth (cm)	Sediment
0-15	Living *Sphagnum*, green.
15-40	Transition zone, *Sphagnum* becoming increasingly humified.
40-163	Dark-brown macromud, fibrous roots, sedge leaves and leaf bases; mountain beech and silver beech leaves common throughout.
163-170	Transiton zone. Light grey silty clay with sedge leaves.
170-180	Light grey silty clay.

APPENDIX II

SPECIES LISTS

IIA PROSPECT HILL BOG SURFACE SPECIES

Quagmire Tarn Bog

Agrostis tenuis
Anisotome aromatica
Anthoxanthum odoratum
Blechnum penna-marina
Bryum sp.
Carex coriacea
C. echinata
C. secta
C. sinclairii
Celmisia gracilenta
Dracophyllum uniflorum
Dracophyllum pronum hybrid
Drosera arcturi
Eleocharis acuta
Epilobium macropus
Epilobium spp.
Galium perpusillum
Gaultheria crassa
Gaultheria sp.
Gentiana sp.
Hebe odora
Hierochloe redolens
Hydrocotyle tripartita
Hypsela rivalis
Myrsine nummularia
Nothofagus menziesii (seedling)
N. solandri var. *cliffortioides* (seedling)
Oreobolus pectinatus
O. strictus
Pernettya macrostigma
Pimelea oreophila
Polytrichum sp.
Potamogeton cheesemanii
Ranunculus lappaceus
Schoenus pauciflorus
Sphagnum cristatum
S. falcatulum

Windy Tarn Bog

Abrotanella caespitosa
Abrotanella sp.
Agrostis tenuis
Anisotome aromatica
Anthoxanthum odoratum
Blechnum procerum
Carex diandra
C. echinata
C. gaudichaudiana
C. sinclairii
Celmisia gracilenta
Chionochloa rubra
Festuca novae-zelandiae
Gaultheria sp.
Gnaphalium paludosum
Hypsela rivalis
Juncus effusus
Juncus sp.
Myriophyllum propinquum
Oreobolus pectinatus
Polytrichum sp.
Ranunculus lappaceus
Ranunculus sp.
Rumex acetosella
Schoenus pauciflorus
Schoenus sp.
Sphagnum cristatum
Uncinia sp.
Viola cunninghamii

IIB UPPER RAKAIA VALLEY FOREST/SCRUB REMNANTS*

Prospect Hill

Very Small Forest/Scrub Remnants on Prospect Hill.

Cordyline australis

Hoheria lyalli

Pseudopanax colensoi

Gaultheria crassa

Rubus cissoides

Sophora microphylla

Fuchsia perscandens

Griselinia littoralis

Dracophyllum longifolium

Polystichum vestitum

Small *Dacrydium bidwillii* stand (20 m diameter, 3-5 m high) across Lake Stream from Prospect Hill.

Main species *Dacrydium bidwillii*

Other species *Coprosma* sp. aff. *parviflora*

Muehlenbeckia complexa

Rubus squarrosus

Hypolepis millefolium

Uncinia sp.

Polystichum vestitum

Sedges

* Species listed in generally decreasing order of abundance.

Forest at Downs Hut.

Main species	*Nothofagus solandri* var. *cliffortioides*
	N. menziesii (scattered)
	Hoheria lyalli
	Griselinia littoralis
Other species	*Fuchsia excorticata*
	Carpodetus serratus
	Pseudopanax colensoi
	Aristotelia serrata
	Coprosma rhamnoides
	Pseudopanax crassifolium
	Coprosma rugosa
	Hebe salicifolia
	Podocarpus nivalis x *hallii*
	Olearia arborescens
	Rubus cissoides
	Coprosma microcarpa
	Coprosma propinqua
Ground	*Astelia nervosa*
	Polystichum vestitum
	Blechnum procerum
	Uncinia uncinata
	Gaultheria antipoda
	Hypolepis millefolium
	Urtica incisa
	Chionochloa conspicua

Forest and Scrub, Upper Rakaia Valley

Forest at Washbourne Hut.

Main species	*Griselinia littoralis*
	Podocarpus hallii
Other species	*Pseudopanax crassifolium*
	Carpodetus serratus
	Hoheria glabrata
	Coprosma linariifolia
	C. sp. aff. *parviflora*
	Myrsine divaricata
	Muehlenbeckia australis
	Rubus schmidelioides
	Sophora microphylla
	Parsonsia capsularis

Jellicoe Stream - two stands of forest on fans.

Main Species		
Stand 1.	*Olearia ilicifolia* (dominant)	
	Phyllocladus alpinus	
	Griselinia littoralis	
	Podocarpus hallii	
Stand 2.	*Phyllocladus alpinus*	} canopy
	Griselinia littoralis	
	Podocarpus hallii	
Other Species	*Myrsine divaricata*	
	Coprosma sp. aff. *parviflora*	
	Coprosma spp.	
	Hypolepis millefolium	
	Pittosporum tenuifolium	
	Pseudopanax colensoi	

Other species (continued)	*P. crassifolium*
	Metrosideros umbellata (rocky bluff)
	Olearia avicenniaefolia (rocky bluff)
	O. arborescens
	Hymenanthera alpina
	Aristotelia fruticosa
	Hebe salicifolia
	Asplenium flaccidum
	A. flabellifolium
	A. richardii
	Uncinia uncinata

Bull Spur Stream - two stands of forest.

Stand 1.

Main Species	*Podocarpus hallii*
	Griselinia littoralis
Other Species	*Carpodetus serratus*
	Coprosma linariifolia
	Coprosma sp. aff. *parviflora*
	Pseudopanax crassifolium
	Pseudowintera colorata
	Pseudopanax simplex
Ground	*Astelia nervosa*
	Uncinia uncinata
	Libertia sp.
	Asplenium richardii
	A. flabellifolium
	Polystichum vestitum
	Urtica incisa
	Uncinia sp.
	Carex sp.

Stand 2.

Main Species	*Phyllocladus alpinus*
	Podocarpus hallii
	Griselinia littoralis
Other Species	*Pittosporum tenuifolium*
	Coprosma propinqua
	Olearia avicenniaefolia
	Dracophyllum longifolium
	Gaultheria crassa
	Coprosma linariifolia
	C. sp.aff. *parviflora*
	Corokia cotoneaster
	Rubus squarrosus
	Clematis australis
Ground	*Asplenium flaccidum*
	Phymatodes diversifolium
	Podocarpus hallii (juvenile)
	Hebe subalpina
	Griselinia littoralis (seedlings)
	Pseudopanax colensoi (juvenile)
	Gaultheria antipoda
	Uncinia uncinata
	Lycopodium varium
	Corybas macranthus

Forest stand near Reischek Hut.

Main Species	*Griselinia littoralis*
	Podocarpus hallii
Other Species	*Hoheria glabrata*
	Pittosporum tenuifolium

Other Species (continued)	*Olearia ilicifolia*
	Olearia avicenniaefolia
	Coprosma linariifolia
	Phyllocladus alpinus
	Pseudopanax crassifolium
	Myrsine divaricata
	Coprosma sp. aff. *parviflora*
	C. propinqua
	C. ciliata
	Rubus schmidelioides
	Archeria traversii
	Libocedrus bidwillii
	Leptospermum scoparium
Ground	*Polystichum vestitum* (dominant)
	Uncinia uncinata
	Urtica incisa
	Poa imbecilla
	Chionochloa conspicua
	Phormium cookianum
	Asplenium richardii

Scrub on glacial moraines near Lyell Hutt (at valley-head).

Shrubs

Main Species	*Podocarpus nivalis*
	Dracophyllum longifolium
	Phyllocladus alpinus
	Coprosma pseudocuneata
Other Species	*Coprosma rugosa*
	Hebe subalpina
	Hymenanthera alpina
	Coprosma dumosa

Other Species (continued)

Myrsine nummularia

Senecio cassinioides

Olearia nummularifolia

Muehlenbeckia axillaris

Dracophyllum uniflorum

Gaultheria crassa

Hoheria glabrata

Parahebe decora

Pittosporum anomalum

Pimelea oreophila

Gaultheria depressa

Coprosma cheesemanii

C. depressa

Aristotelia fruticosa

Griselinia littoralis

Cyathodes fraseri

Coprosma sp. aff. *parviflora*

Pseudopanax colensoi

Coprosma ciliata

C. pumila

Dracophyllum kirkii

Myrsine divaricata

Senecio eleagnifolius

Grasses and Rushes

Poa colensoi

Uncinia divaricata

Luzula sp.

Agropyron scabrum

Chionochloa flavescens

Phormium cookianum (agave)

Chionochloa pallens

Ferns and Mosses

Blechnum penna-marina

Polystichum vestitum

P. cystostegia

Rhacomitrium lanuginosum

R. crispulum

Hypnum cupressiforme

Lycopodium fastigiatum

Forbs

Epilobium melanocaulon

Wahlenbergia albomarginata

Coriaria angustissima

Raoulia spp.

R. glabra

Acaena anserinifolia

Ranunculus lyalli

Senecio bellidioides

Viola cunninghamii

Helichrysum bellidioides

Aciphylla scott-thompsonii

Celmisia coriacea

Geum parviflorum

Table 3A

PLANTS

A	*Accarina*
Ac	*Acaena*
Al	Araliaceae
Ar	*Aristotelia*
Az	*Azolla*
Ca	*Casuarina*
Ch	Chenopodiaceae
Co	*Coriaria*
Cy	Caryophyllaceae
D	*Dacrydium bidwillii* type
Dr	*Dracophyllum*
E	Elaeocarpaceae
Eh	*Elaeocarpus hookerianus*
Ep	*Epilobium*
G	*Griselinia*
Ga	*Galium*
Ge	*Gentiana*
Gr	*Geranium*
Gu	*Gunnera*
H	*Hoheria*
Ha	*Haloragis*
Hm	Hymenophyllaceae
Hy	*Hydrocotyle*
L	*Leptospermum*
Li	*Libocedrus*
Ly	*Lycopodium*
M	*Metrosideros*
Mo	*Myriophyllum*
Mr	Myrtaceae
Mu	*Muehlenbeckia*
My	*Myrsine*
Nf	*Nothofagus fusca*
Nm	*Nothofagus menziesii*
Ns	*Nothofagus solandri* var. *cliffortioides*
O	Onagraceae
P	*Plagianthus*
Pa	Papilionaceae
Pd	*Podocarpus dacrydioides*
Ph	*Podocarpus hallii*
Po	*Plantago*
Pr	*Phormium*
Ps	*Phymatodes*
Pt	*Potamogeton*
Pw	*Pseudowintera*
Px	*Pseudopanax*
Py	*Phyllocladus*
R	Rosaceae
Ra	Ranunculaceae
T	*Tupeia*
Te	Tetrad
Th	Thymelaeaceae
U	Umbelliferae
W	*Weinmannia*

SEDIMENTS

- micromud
- macromud
- silt and sand
- clay
- rootlets
- water
- *Sphagnum* peat
- charcoal
- sedge leaves or peat
- fibrous, or fibrous roots
- fibrous sedge peat
- rock

COLOURS

Y	yellow
B	brown
G	grey
U	blue
R	red
O	orange
X	black
L	light
D	dark

SITES

QT	Quagmire Tarn
WT	Windy Tarn
MS	Mt. Somers
BS	Blondin Stream
RP	Raupo Pond
SB	Springs Bog

A.P. Arboreal pollen

N.A.P. Non arboreal polle

L.D.D. Long distance dispersal

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Fig. 6.1 QUAGMIRE TARN alt. 740 m

NZMS1 LAKE HERON S73
FIRST EDITION 1959
G.R. 664821

POLLEN SUM = TOTAL POLLEN COUNTED EXCL. AQUATICS & SPORES & UMBELLIFERAE

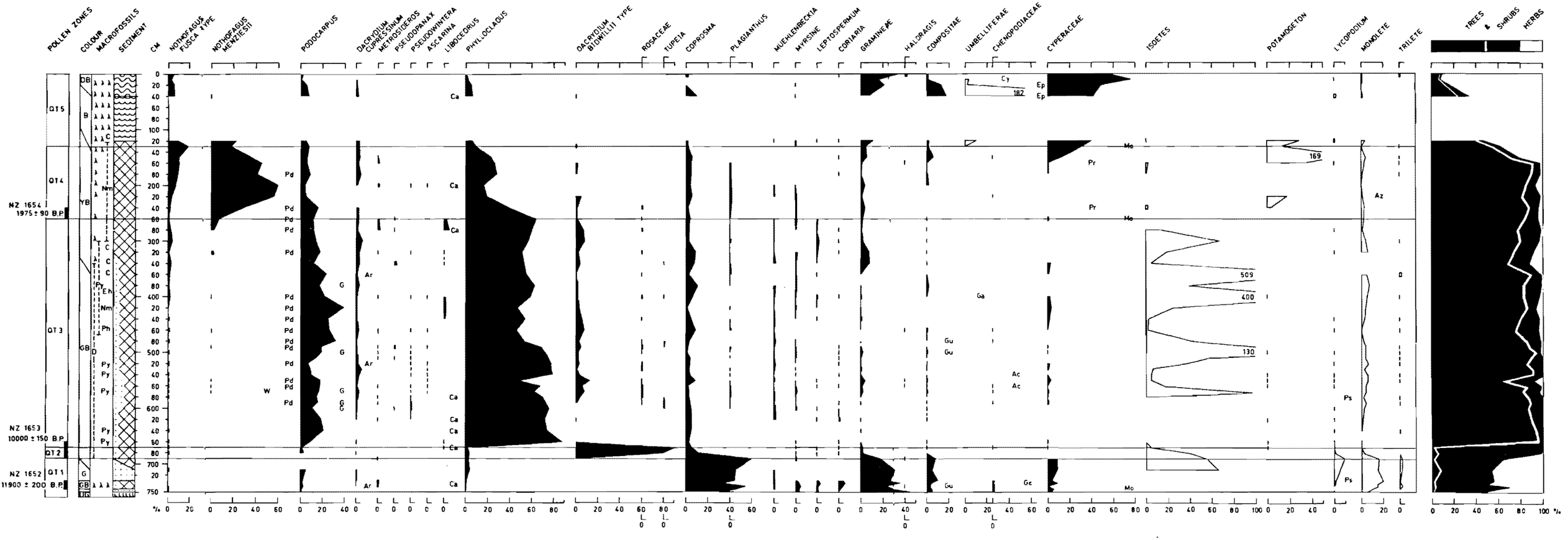


Fig. 6.2 QUAGMIRE TARN 750 cm - 680 cm

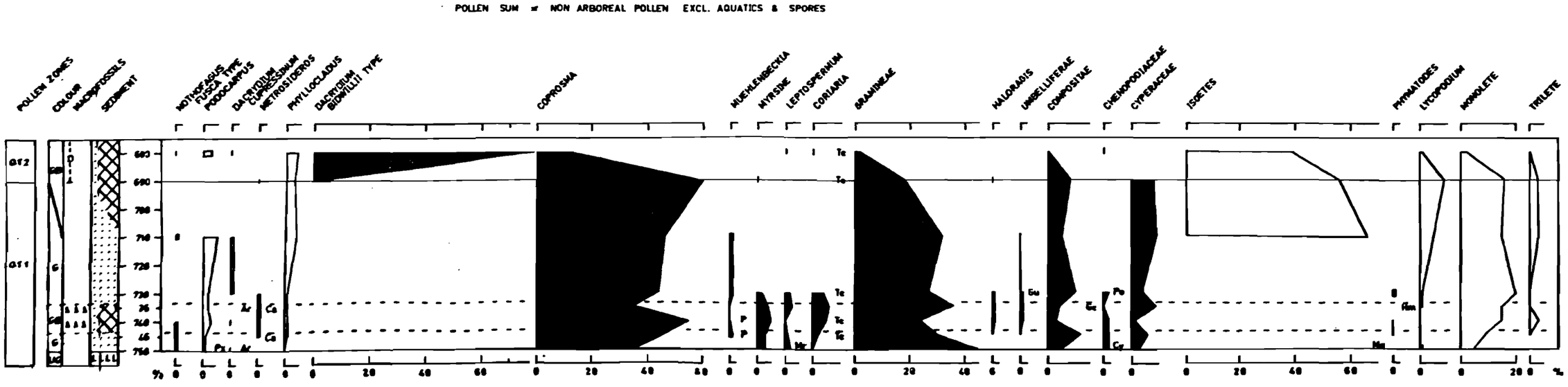


Fig. 6.4

QUAGMIRE TARN 0 cm - 180 cm

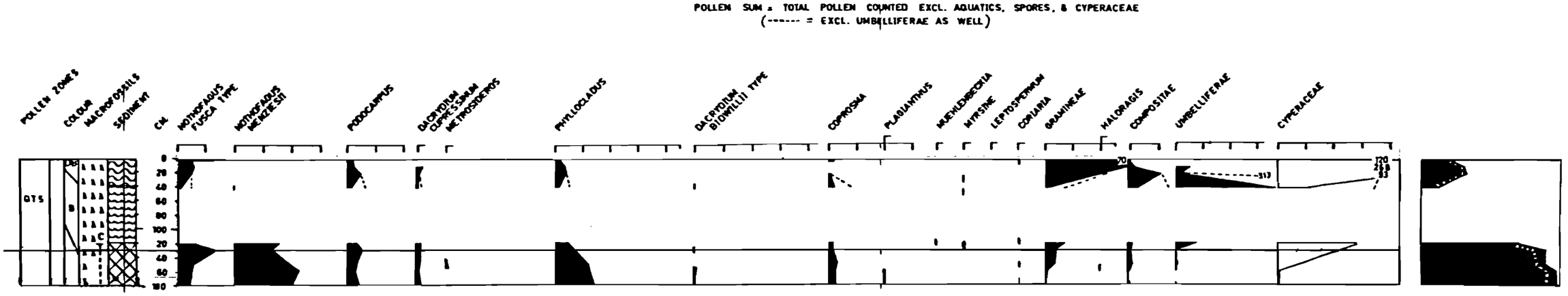


Fig. 7.1 WINDY TARN alt. 750 m

NZMS 1 LAKE HERON S73
FIRST EDITION 1969
G.R. 654840

POLLEN SUM = TOTAL POLLEN COUNTED EXCL. AQUATICS & SPORES & HALORAGIS

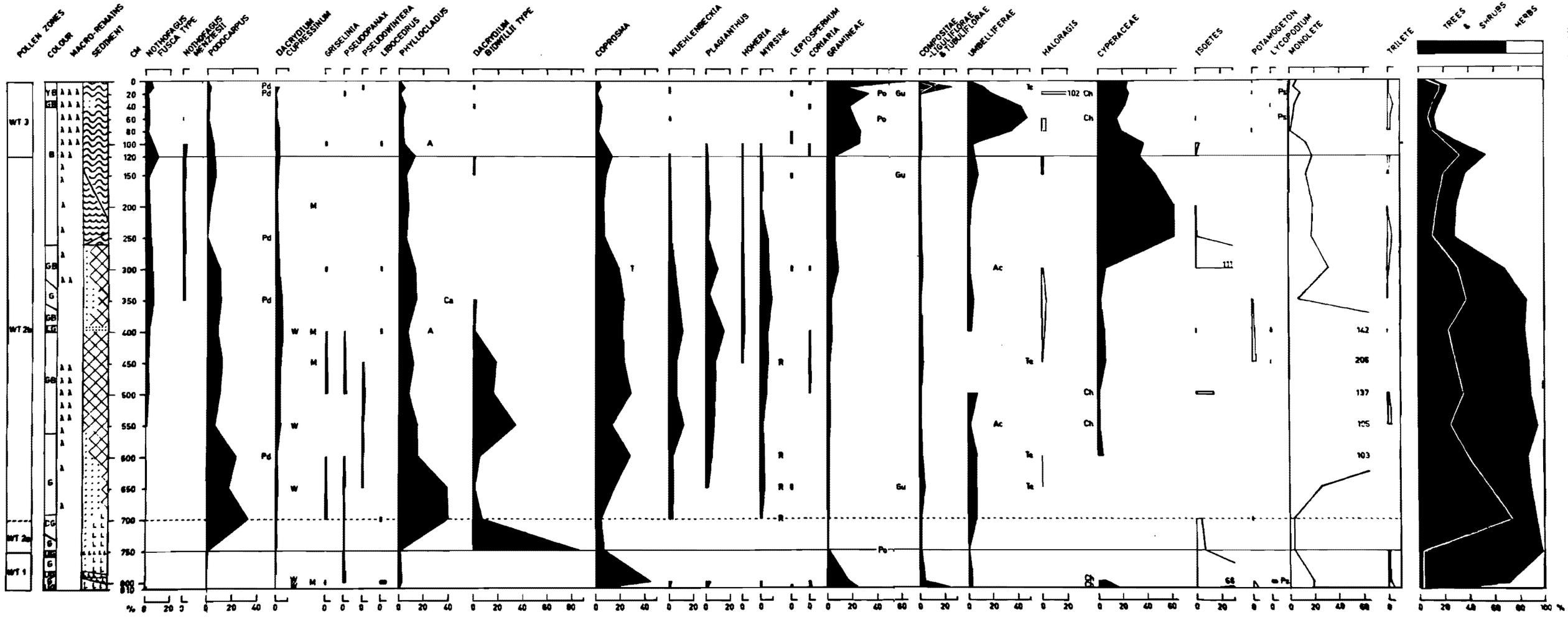


Fig. 7.2 WINDY TARN 0 - 400 cm

NZMS 1 LAKE HERON S73
FIRST EDITION 1969
G.R. 654840

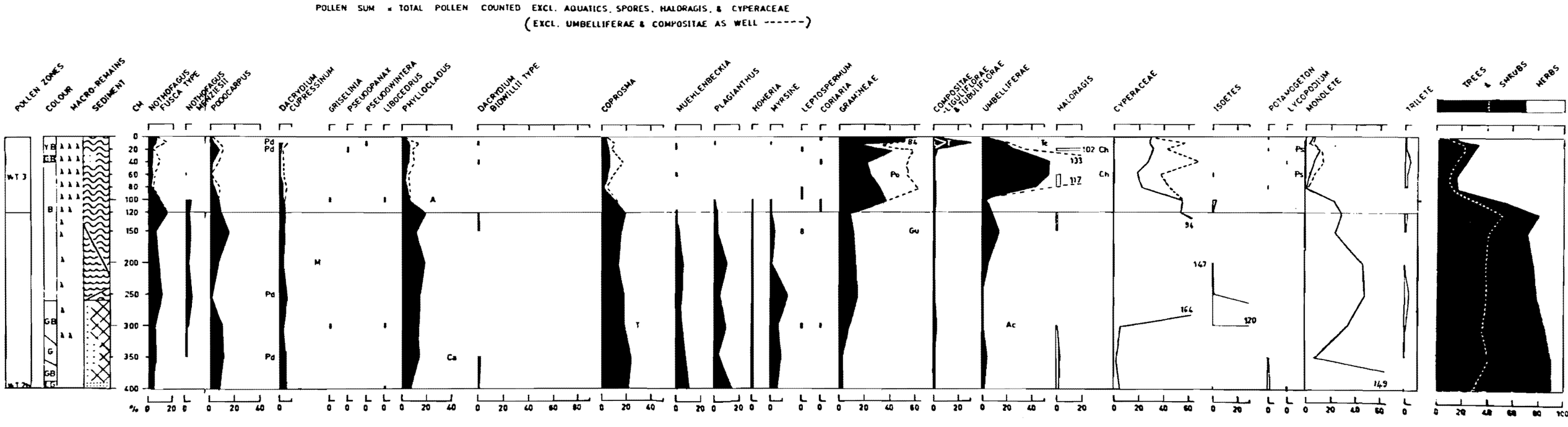


Fig. 8.1 MOUNT SOMERS alt. 1273 m

NZMS 1 MT SOMERS S81
SECOND EDITION 1970
G.R. 858459

POLLEN SUM = TOTAL POLLEN COUNTED EXCLUDING AQUATICS & SPORES

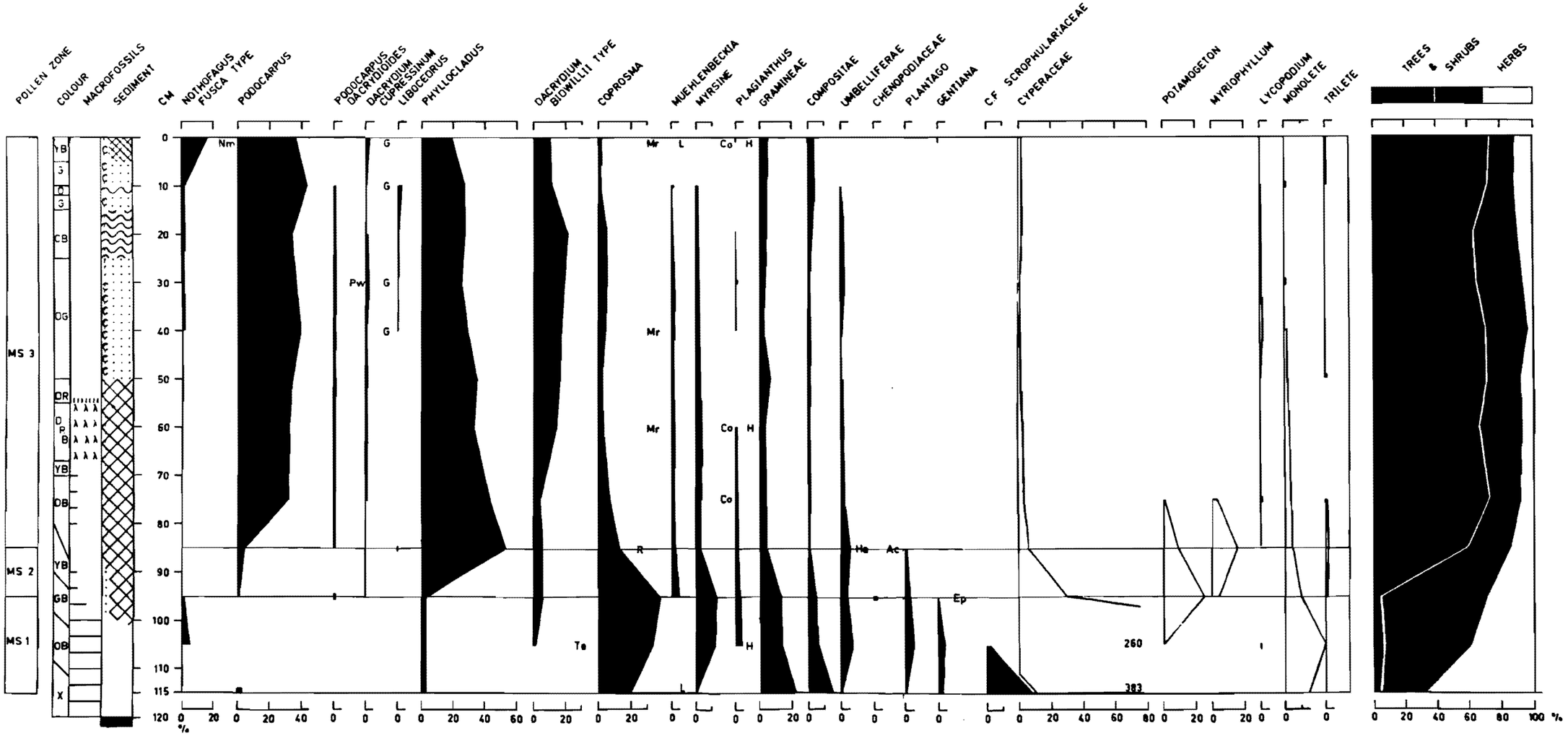


Fig. 8.2 MOUNT SOMERS (N.A.P.) alt. 1 273 m

NZMS 1 MT SOMERS S 81
SECOND EDITION 1970
G.R 858459

POLLEN SUM = NON ARBOREAL POLLEN EXCLUDING AQUATICS & SPORES

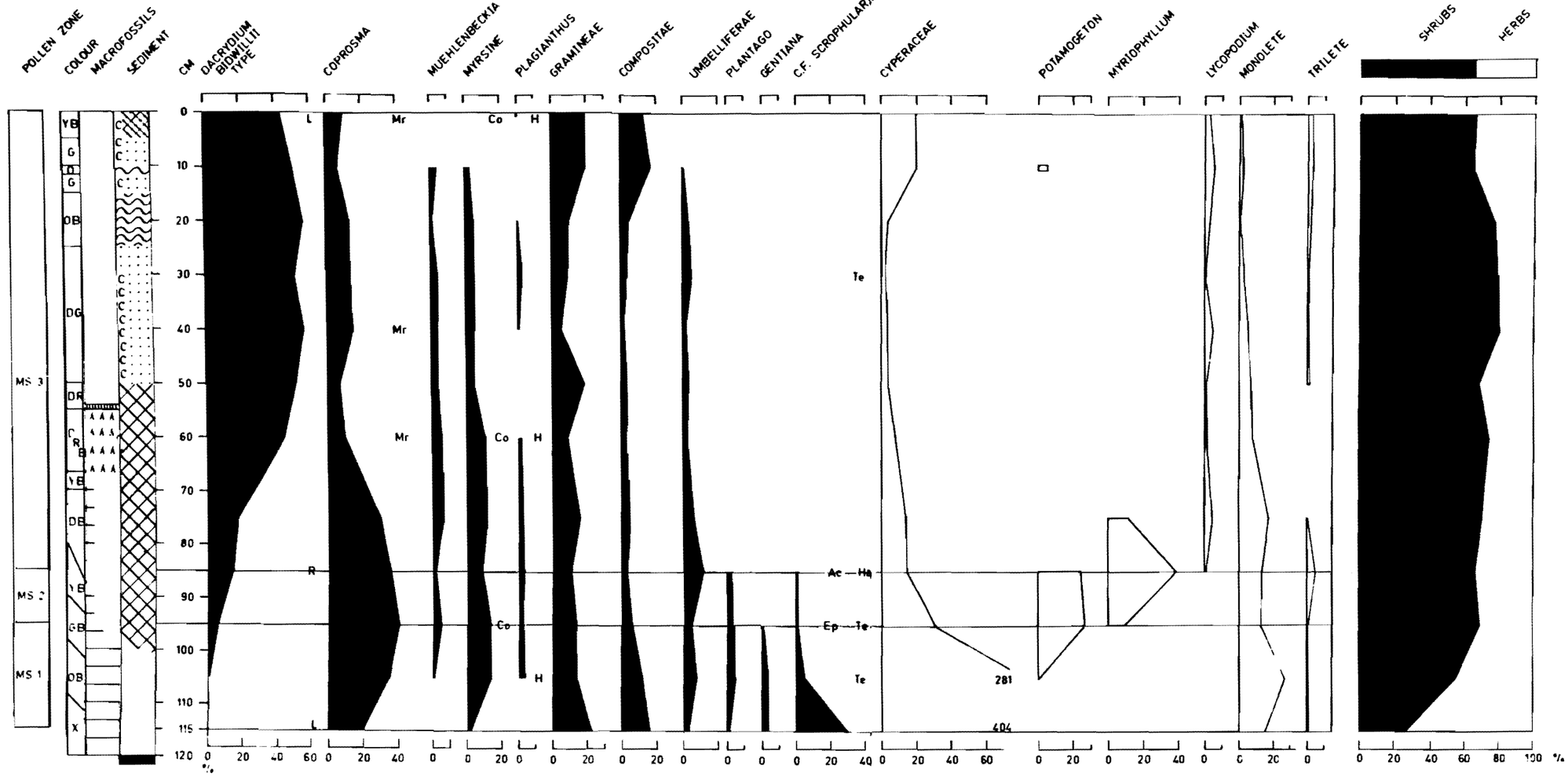


Fig. 9.1 BLONDIN STREAM alt. 545 m

NZMS 1 M.T SOMERS S 81
SECOND EDITION 1970
G.R. 803399

POLLEN SUM = TOTAL POLLEN COUNTED EXCLUDING AQUATICS & SPORES

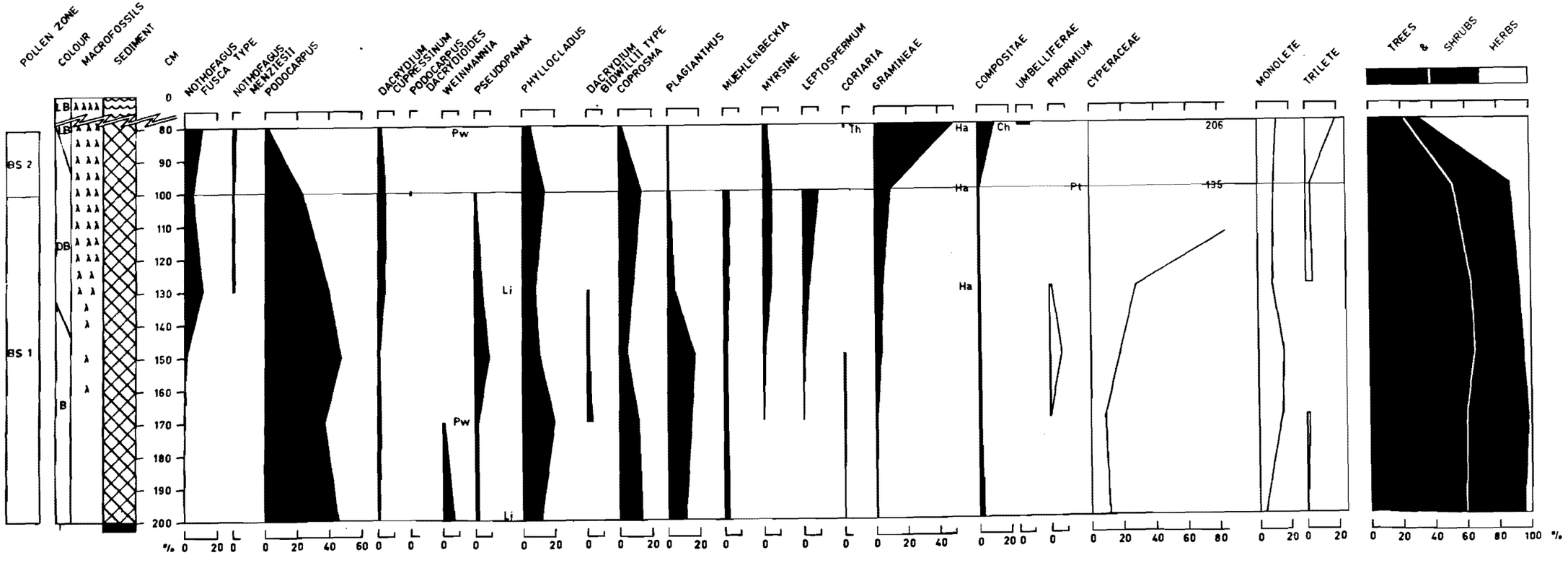


Fig. 10.1 **RAUPO POND** alt. 579 m

NZMS 1 DAMPIER S60
FIRST EDITION 1965
G.R. 681486

POLLEN SUM = TOTAL POLLEN COUNTED EXCL. AQUATICS & SPORES

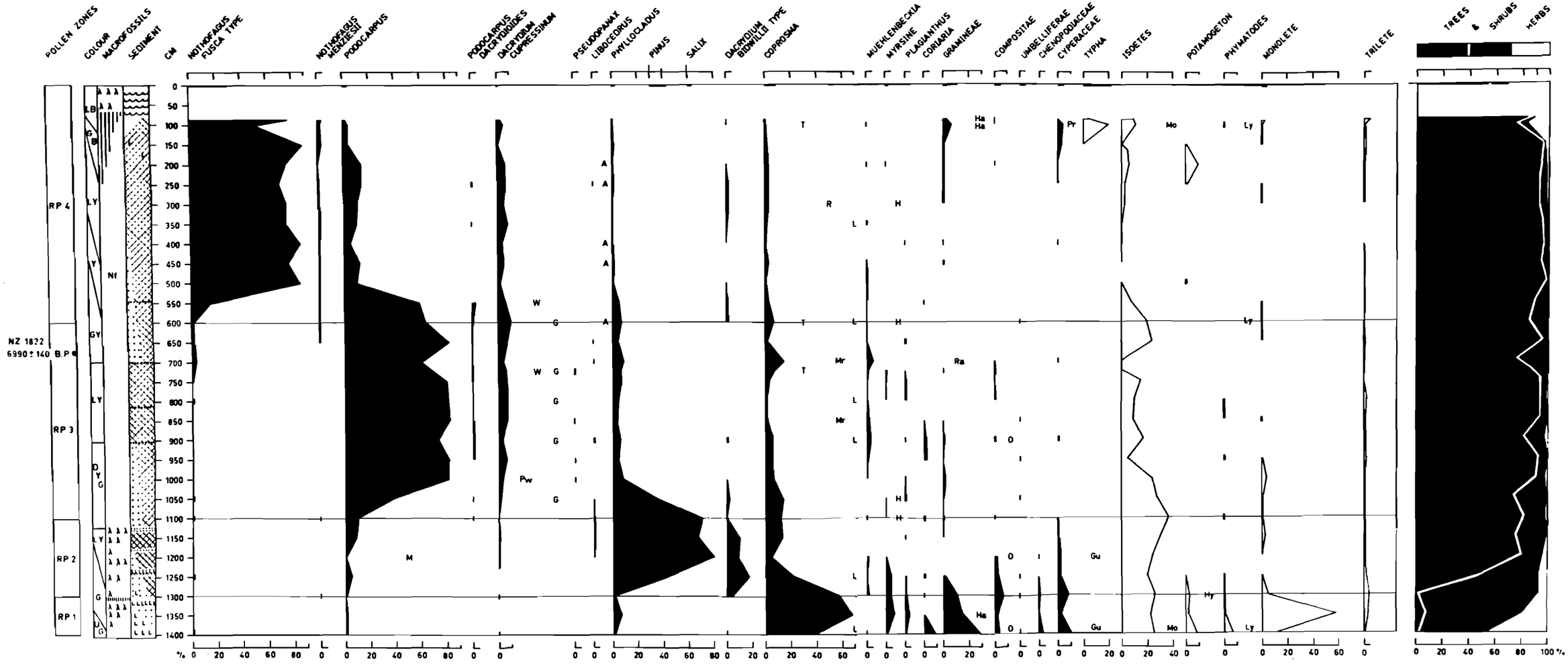
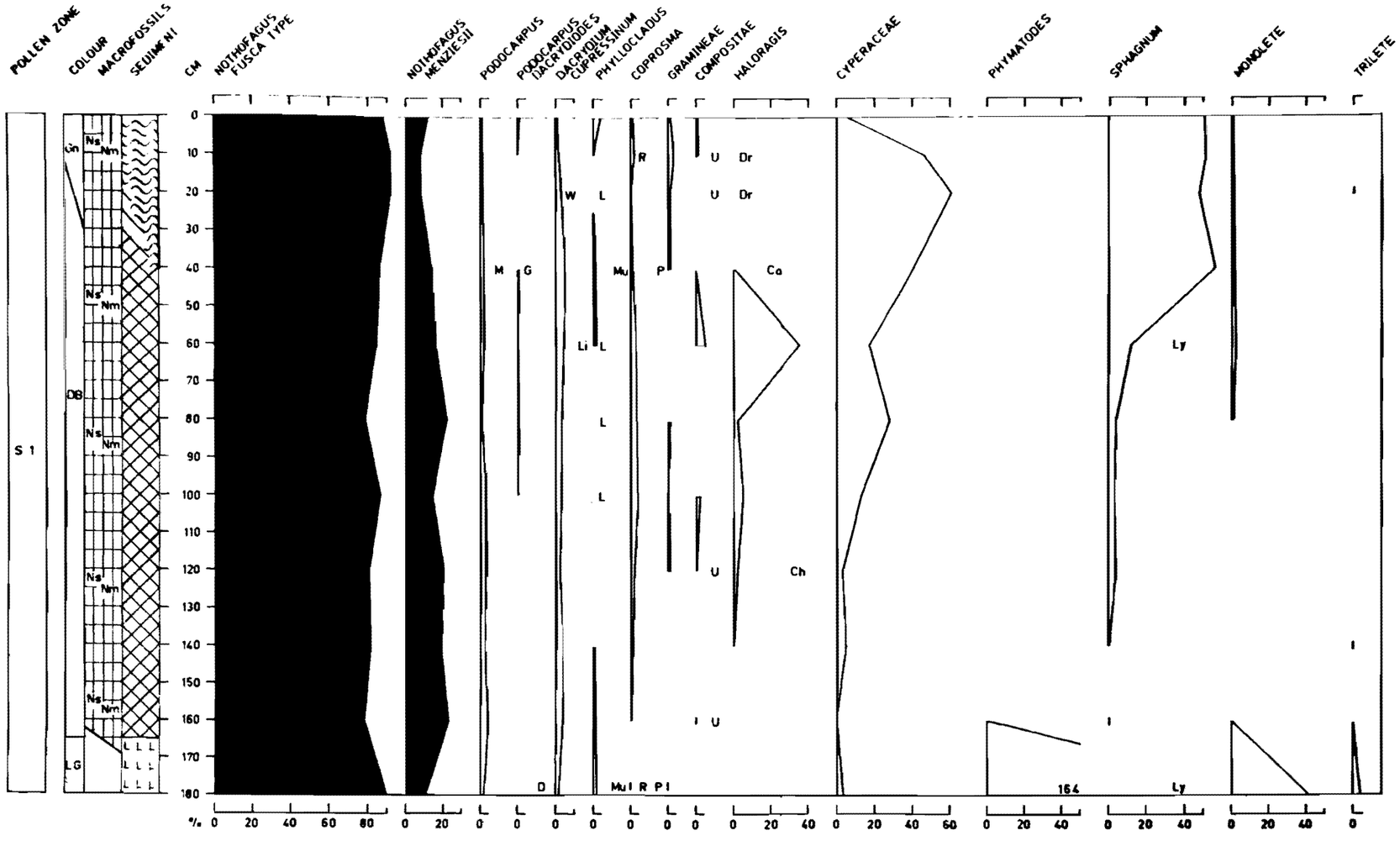


Fig. 11.1 SPRINGS BOG alt. 604 m

NZMS 1 LAKE SUMNER S53
FOURTH EDITION 1972
G.R. 485593

POLLEN SUM = TOTAL POLLEN OF NOTHOFAGUS



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Journal of the Royal Society of New Zealand, 1975, Vol. 5, No. 4, pp. 463-477, 11 figs

Moraines of the Upper Rakaia Valley

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Abstract

Moraines in the Upper Rakaia Valley record glacial activity at intervals between about 12,000 yr BP and the last few decades. The Lake Stream and Jagged Stream advances occurred probably between 11,900 and 10,000 yr BP and extended 29 km and 21 km, respectively, from the valley head. One or more renewed advances occurred more than 4,500 yr BP and gave rise to the complex of drift near the Reischek River only 9 km from the valley head. Another phase of glacial activity began 4,500 yr BP (at least) and constructed moraines on the Meins Knob ridge, but no date is available for its end. Further advances formed a complex of moraines near the Lyell Hut more than 1,000 years ago. The most recent series of glacial events formed the Whitcombe group of moraines within the last few centuries.

Introduction

The Lyell and Ramsay Glaciers, at the head of the Upper Rakaia Valley, are the northernmost large glaciers in New Zealand (Fig. 1). Their névés and those of their tributary glaciers lie along about 18 km of the main divide of the Southern Alps. The glaciers are overlooked by only 5 peaks of 2500 m or more, but there are at least 30 peaks of 2000 m and many lesser peaks. The Lyell glacier is about 6.0 km long and the Ramsay glacier about 8.5 km long. The termini of the glaciers are at 1006 m and 945 m a.s.l., respectively. A third, smaller glacier, the Reischek, rising in the Arrowsmith Range, has also been a contributor to the glacial history of the area. So too have other glaciers in tributary valleys on both sides of the main valley. They include the Jagged Stream on the south bank, and Louper, Duncan's, Cattle, and Totara Creeks on the north bank. The last four have not been studied.

The streams draining from the Lyell and Ramsay Glaciers join to form the Rakaia River, which flows eastward down a wide valley between rugged mountain ranges. As soon as it leaves the glaciers the river flows in braided channels on its gravel bed. Apart from the tributaries mentioned above it is joined by several other streams, including the Lake Stream on the south bank (Fig. 2). All of the major tributaries have built fans out into the valley. The Rakaia River is joined by the Mathias River near Manuka Point, 39 km from the valley head, and 13 km further on is the confluence with the Wilberforce River, near Mt. Algidus. The valley upstream of Manuka Point will be regarded as the Upper Rakaia Valley for the purposes of this paper, and the area between Manuka Point and the eastern side of the Rakaia Gorge will be referred to as the Middle Rakaia Basin.

Between Manuka Point and the modern glaciers many eroded remnants of moraines are present. The purpose of this paper is to describe these moraines and related features and to outline a chronology of glacial events in the area.

The glacial geology of the Middle Rakaia Basin has been well described by Speight (1934), Soons (1963), Soons and Gullentops (1973), and Carryer (1967). In particular, information concerning the last major advances (Acheron 1, 2, 3) of the Otira glaciation, which left moraines near Lake Coleridge and the Acheron River (Soons 1963), has relevance to the present study. Speight (1911, 1934) briefly mentioned some of the moraines in the Upper Rakaia Valley but they have

not previously been mapped or described in detail. H. W. Keene and P. J. Oliver (Sheet 81, Mount Somers. "Geological Map of New Zealand 1:63,360". New Zealand Department of Scientific and Industrial Research (in preparation)), in their description of the glacial geology of the Lake Heron basin, refer to moraines around the southern end of Lake Heron, formed by a lobe of the Rakaia Glacier which pushed southwards up the Lake Stream valley. The Lake Heron moraines are correlated with the Acheron moraines near Lake Coleridge.

FIG. 1.—Locality map of the head of the Rakaia Valley showing distribution of moraines.

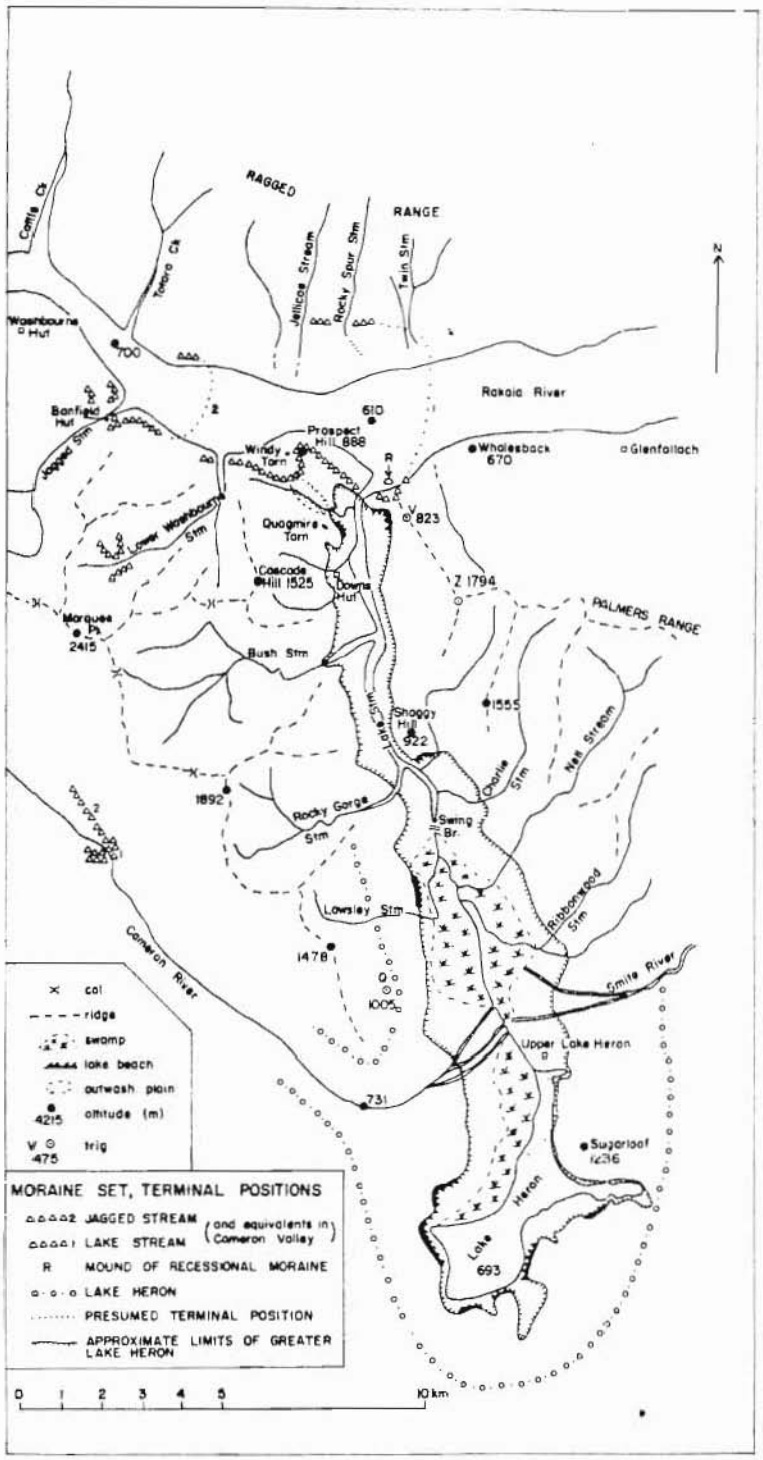


FIG. 2.—The Lake Stream and Prospect Hill areas showing moraines and extent of "Greater Lake Heron".

The documentation used to develop a chronology of glacial activity near the valley head in recent centuries is outlined in Burrows and Maunder (1975).

LAKE HERON MORAINES

Glacial features are well preserved on the promontory known as Prospect Hill (Fig. 2), which projects into the Rakaia Valley just west of the mouth of the Lake Stream. The Lake Heron advances are represented by streamlined, ice-smoothed surfaces, ice-cut benches, some ground moraine and by recessional end moraine. These features have only partially been modified by subsequent glacial and fluvial activity (Fig. 3). The glacial features form an extensive area of downland between

FIG. 3.—Prospect Hill (right middle ground). Lake Heron surface in foreground and on right. The Lake Stream moraine and outwash plain show clearly in the middle ground.

Prospect Hill proper and Cascade Hill. The upper limit of Lake Heron ice on Cascade Hill may have lain at about 1250 m altitude, where there is a prominent bench. An approximate ice limit at 1250 m is estimated by using a value of about 25 m/km for the gradient of the surface of the glacier, derived from the slope of the clearly-expressed Lake Heron lateral moraines between the terminus and Trig Q (Fig. 2). The ice level might have been higher on Cascade Hill, however, because the hill shows signs of having been overtopped by ice. Other benches on Cascade Hill below 1250 m probably represent limits of the ice during shrinkage, and deposits of recessional moraine are present near the floor of the Lake Stream Valley, e.g. near Lawsley Stream (Fig. 2).

Sediments in "Quagmire" tarn* on the Lake Heron surface (S73/663821)† and "Windy" tarn* on the younger Lake Stream surface (S73/654840) have been examined by pollen and plant macrofossil analysis, and several samples were taken from the former locality for radiocarbon assay (J. B. Russell, Aranuian pollen diagrams from central South Island. Ph.D. Thesis, University of Canterbury (in preparation)). A full account of the pollen and macrofossil analyses will be published elsewhere.

The lowermost sediments in "Quagmire" tarn consist of a sequence: inorganic→slightly organic→inorganic→organic. The lowest organic horizon is dated

*Provisional name, forwarded to the New Zealand Geographic Board for its approval. All such names are placed here within quotation marks.

†The two map sheets covering the area are N.Z.M.S. 1, Godley (S72) and Lake Heron (S73), published in 1970 and 1969 respectively.

11,900 ± 200 yr BP (N.Z. 1652). Lake Heron ice had thus retreated from Prospect Hill by at least about 12,000 yr BP and possibly a thousand or more years earlier (note that all radiocarbon dates are given using the old standard for the half-life of ^{14}C and without correction for secular variation). This dating is reasonably consistent with other dates near the end of the last main Otiran advance. For example, in the Waiau River Valley in North Canterbury, a late stage of the glaciation was dated at 14,100 ± 220 yr BP (N.Z. 532) (Suggate 1965) and, farther up the same valley, sediments were being deposited in a lake probably dammed by a glacier 13,309 ± 203 yr BP (KI 354-1) (Clayton 1965). In South Westland, at Omoeroa Bluff a glacier extended beyond the present coastline at 13,950 ± 140 yr BP (N.Z. 479) (Wardle 1973), but at Paringa a glacier was retreating rapidly 13,400 ± 150 yr BP (N.Z. 531) (Suggate 1968).

LAKE STREAM AND JAGGED STREAM MORAINES

Lake Stream Advance

The Rakaia Glacier later readvanced and deposited a well-marked moraine (with two crests only a few metres apart) on the western and northern flanks of Prospect Hill and the downland immediately south of it (Figs. 2, 3) and masked some of the Lake Heron advance features there with fresher deposits. In the Lower Washbourne Stream Valley (known locally as Thompsons Creek), at least 150 m of glacio-fluvial deposits accumulated against the ice (Fig. 4), the surface of which lay at 859 m, while meltwater escaped down channels on the southern side of the

FIG. 4.—Fluvio-glacial deposits of Lake Stream age in the east bank of Lower Washbourne Stream.

Prospect Hill downland, into the Lake Stream Valley. This alluvium can be seen resting against till at S73/638828. Glaciers at the head of Lower Washbourne Stream gave rise to the outwash and meltwater and built moraines at 1520 m which are contemporaneous with the Lake Stream moraine. Drift from the Lake Stream advance is plastered onto the hillside just west of the Washbourne stream confluence with the Rakaia Valley (S73/630836). A lobe of ice was pushed onto the Prospect Hill downland, 762 m a.s.l., and meltwater from it formed a small outwash plain, before entering the ice-free Lake Stream Valley. A field of drumlin-like hillocks.

formed contemporaneously, is present on the proximal side of the moraine loop. From a height of 864 m a.s.l. on Prospect Hill a lateral moraine slopes down to about 700 m at the mouth of the Lake Stream. A lake which existed while the ice blocked the Lake Stream Valley (Fig. 2) formed wave-cut beaches on the east side of Prospect Hill and on the ridge and slopes beneath Trig V, east of the Lake Stream. The highest beach which can plainly be seen is at 737 m on the ridge near Trig V but this probably dates from the retreat phase after the Lake Heron advance. On the Prospect Hill downland, a well-marked beach is present at 700 m, near "Quagmire" tarn, and another at 689 m. Others are evident at these and lower altitudes on the slopes below Trig V. The lake must have extended right up the Lake Stream Valley to Lake Heron and covered an area of at least 4600 ha. Beaches on Lake Heron recessional moraine between Rocky Gorge stream and Lawsley Stream, at 713 m, and round the shores of Lake Heron at about 700 m and 712 m, mark limits of this lake. The large swamps between Lake Heron and the swing bridge across the Lake Stream (S73/693739) (Fig. 2) lie over deposits of lake silt into which the Lake Stream is incised. Recent fan-building has filled some of the former lake basin so that its area is known only approximately.

Little moraine from the Lake Stream advance is present on the southern side of the Rakaia Valley below the Lake Stream confluence. Small ridges at about 670 m (S73/676826) mark the position of a minor spillover of ice south into the Lake Stream Valley (Fig. 2). A small ridge of till over bedrock (at S73/683829) may mark the terminal position of the glacier and a small hillock of recessional moraine behind it projects about 12 m above the Lake Stream riverbed gravel at S73/683835 (Fig. 5). About 2 m of loess covers this mound and from 0.5-2 m of loess is present on the Lake Stream surface on Prospect Hill.

FIG. 3—Rakaia Valley from slopes of Prospect Hill. Lake Stream moraine in centre, showing possible terminal position T and the small hillock of recessional moraine R in the bed of the Lake Stream. Glenfalloch Station in distance.

On the northern side of the Rakaia Valley the terminus may have extended a little further down-valley, on the evidence of fragmentary benches at about 820 m a.s.l. just downstream of each of Jellicoe and Rocky Spur Streams and a slight indication of a similar feature at Twin Streams (Fig. 2, 6). A cursory examination

FIG. 6.—Looking across the Rakaia Valley to benches (arrows) at Jellicoe Stream (left) and Rocky Spur Stream which mark the limits of Lake Stream ice.

of the material in these benches showed that it consists of a till-like accumulation of large boulders, cobbles and pebbles in a matrix of finer material, under hummocky surfaces with projecting boulders. The benches are believed to represent the upper limit of Lake Stream ice on this side of the valley. The glacier could not have extended more than a few kilometres beyond Rocky Spur Stream at this time on the north side of the valley, but the terminus maintained a position across the mouth of the Lake Stream Valley long enough for the cutting of the uppermost lake beaches, after which the ice gradually shrank downward, with halts for the cutting of more beaches at successively lower levels. There is no evidence for the existence of a massive moraine dam and the slow shrinkage is presumed to have resulted from the presence of a glacier trunk thickly covered by surface moraine.

Few other traces exist of moraine deposited in Lake Stream time. A short section of moraine, which almost certainly was deposited then, is present on "High Moraine Bluff", the end of the long ridge extending west from Mt Murray, above the Reischek Valley (Figs. 1, 7, 10). Several moraine ridges occur, the highest at about 1430 m. The general ice level in the Upper Rakaia Valley at this point must have lain at about the same altitude. By projecting the slope of the moraine (ca. 150 m/km) up-valley, it may be inferred that the *névé* of the Reischek glacier lay at about 2000 m. Ice would have filled the heads of the Lyell and Ramsay Valleys probably to higher altitudes. The gradient of the glacier from the Reischek Valley to the Lake Stream was about 43 m/km. It is surprising that so little of the Lake Stream glacial drift remains along the walls of the Rakaia Valley. Its absence may be attributed partly to erosion by the river, but possibly also to burial by alluvium and hillslope erosion on the steep valley walls.

It is believed that the Lake Stream advance occurred later than about 11,900 ± 200 yr BP (N.Z. 1652) and earlier than 10,000 ± 150 yr BP (N.Z. 1653). The older date was obtained from the lowest organic horizon in the sediments of "Quagmire" tarn. The subsequent deposition of inorganic sediments, probably loessic, is believed to have occurred during the Lake Stream advance (and possibly also the later Jagged Stream advance). The younger date was obtained from just above the inorganic sediment. The data from pollen analysis (Russell, in preparation) are

FIG. 7.—"High Moraine Bluff" at the Reischek River from the base of Meins Knob. Moraines are marked by arrows.

consistent with this interpretation. A date of 9,520 ± 95 yr BP (N.Z. 688) from the adjacent Cameron Valley (Burrows 1972) post-dates two glacial maxima in that valley, the Wildman 1 and Wildman 2 advances, which are correlated, respectively, with the Lake Stream and Jagged Stream advances. In "Windy" tarn the lower organic horizon is missing, and all the inorganic sediments therefore appear to date from recessional stages of the Lake Stream advance and the subsequent Jagged Stream advance.

FIG. 8.—Jagged Stream moraine from the Rakaia riverbed. Jagged Stream Valley in background.

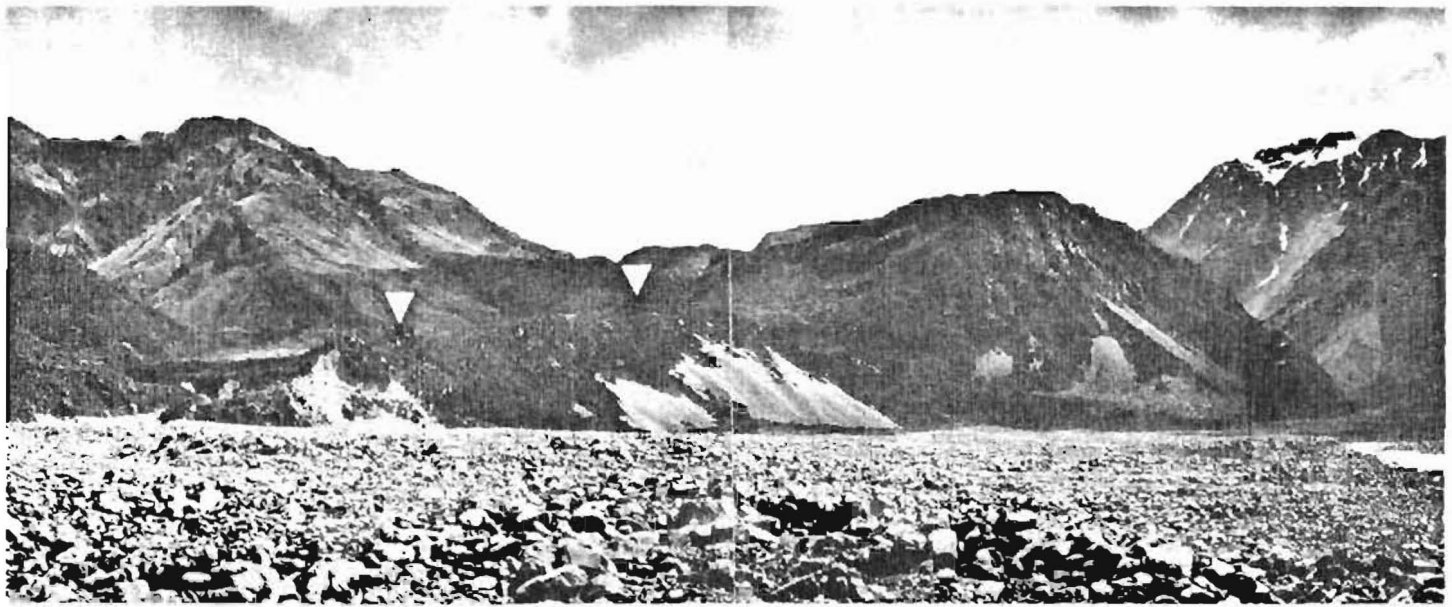


FIG. 9.—Moraine ridge at the Reischek River (arrows). Meins Knob ridge in centre and right background.

Jagged Stream Advance

The evidence for the Jagged Stream advance exists mainly in the form of a portion of lateral moraine (at 737 m a.s.l.) down-valley from the Jagged Stream and moraine benches at slightly higher altitude just west of the Jagged Valley. The lateral ridge east of Jagged Stream falls, in 0.8 km, from 737 m to 695 m before disappearing under a scree (Fig. 8). A low, bouldery ridge at S73/623842 may represent the terminal position. Ice from the Jagged Valley was confluent with the Rakaia ice at this time. High-level moraines at 1520 m beneath Bastion Peak may be of Jagged Stream age, but they could have been formed in Lake Stream time.

Few other traces of the Jagged Stream advance survive. They include a short portion of lateral moraine at about 730 m on the hillside near Totara Creek on the north side of the Rakaia valley and another short section of lateral moraine at about 1200 m on the slopes between Duncans and Louper Creeks, also on the north side of the valley. The lowermost moraines on the "High Moraine Bluff" may have been formed during this advance.

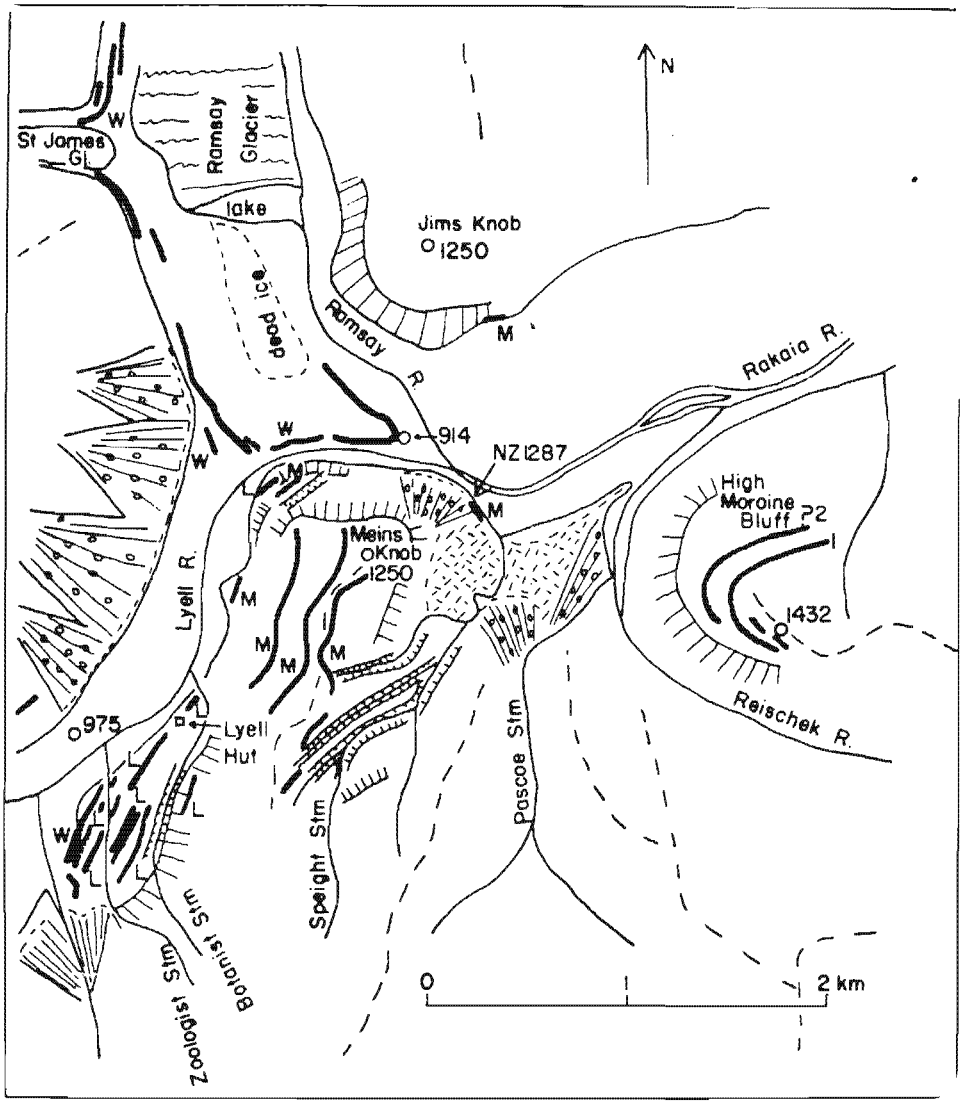
THE REISCHEK AND MEINS KNOB MORAINES

Reischek Moraines

All glacial deposits in the Upper Rakaia Valley formed subsequent to the Jagged Stream advance are found near or upstream of the Reischek Valley. Although no well-defined moraines are present to indicate clearly the course of events in the area between the Reischek River and the long Meins Knob ridge, there are indications that the glacial history has been complex. A moraine ridge occurs (with its crest at about 975 m a.s.l.) between the Reischek and "Speight" Streams (Fig. 9). A lower ridge curves toward the mouth of the Reischek Valley. More drift is present beneath the steep eastern faces of Meins Knob. The drift so far described in this area is placed in the Reischek group of moraines, originating when the combined ice of the Lyell, Ramsay (and possibly also the Reischek) Glaciers lay here, and the terminus of the glacier almost certainly lay downstream of the Reischek Valley. Lyell ice spilt over the top of the Meins Knob ridge at this time. The advance(s) occurred earlier than 4,500 yr BP. It seems likely that the Rakaia river has subsequently destroyed some of the Reischek moraines.

Meins Knob Moraines

The earliest and highest moraines of the subsequent Meins Knob advances are well preserved on the summit of the Meins Knob ridge. Other lateral moraines in the Lyell Valley are well below this level (Fig. 10). All but one of the ridges were formed by the Lyell Glacier. It is likely that, during the early Meins Knob advances the confluent ice of Lyell and Ramsay Glaciers extended some distance east of Meins Knob. At the base of Meins Knob (S72/493862), just above river level, an exposure of ground moraine (Table 1), (Fig. 11) contains abundant fossil wood. A sample of the wood is dated 4,540 ± 105 yr BP. (N.Z. 1287) and inferred as recording an extensive advance after a period of glacial quiescence.



LEGEND

- Ridge
- 0975 Altitude (m)
- Colluvial cone / Alluvial fan
- Steep rock
- Gorge
- Moraine ridge
- W Whitcombe Moraines
- L Lyell Moraines
- M Meins Knob Moraines
- Reischek Drift
- P2 Jagged Stream Moraine
- I Lake Stream Moraine
- NZ1287 Radiocarbon date

FIG. 10.—The Meins Knob-Reischek River area showing the distribution of moraines.

FIG. 11.—Exposure at the base of Meins Knob showing wood embedded in till (N.Z. 1287, 4540 ± 105 yr BP)

TABLE 1.—Exposure of Till with Wood. Northeast of Meins Knob.

	Talus.
1.2 m	Coarse greywacke alluvium
6.0 m+	Ground moraine. Matrix of sand, silt with angular greywacke pebbles, cobbles and a few large boulders. Some argillite clasts present. Abraded wood occurs throughout.
	Descends below river level.

A low ridge of lateral moraine at the northeast corner of Meins Knob is immediately adjacent to the exposure and appears to have been deposited at the same time as the ground moraine. A similar ridge is present at the foot of Jims Knob, immediately opposite.

The dated material records an early advance in Meins Knob time, when ice filled the Lyell Valley to the summit of the Meins Knob ridge. The largest tree stem seen (*Podocarpus hallii*) was 40 cm in diameter and is judged to have been at least 200 years of age when it died. Other species present include the shrubs *Podocarpus nivalis* (three samples) and *Phyllocladus alpinus* (twelve samples). A well-developed forest, at least 200 years old, on Meins Knob was destroyed by the early Meins Knob advance. The wood had been strongly abraded before being imbedded in till. *Podocarpus hallii* occurred on Meins Knob in modern times until removed by fire about 1900 A.D., but it is not present in the Lyell Valley proper.

A notch on the northwest side of Meins Knob represents the position of an ice-marginal channel cut during the Meins Knob advances. Parallel with it, at 1036 m a.s.l., is a moraine which was formed during a late phase in the series of advances.

The last Meins Knob advance of the Lyell Glacier formed a small moraine above bedrock about 0.8 km upstream of the northwest corner of Meins Knob (Fig. 10). No date is available for the end of the Meins Knob advances. The end of deposition of the subsequent complex group of Lyell moraines probably occurred more than a thousand years ago, so that the Meins Knob advances may have ended at least twice as long ago.

Wardle (1973) obtained dates of 2,570 ± 75 yr BP, 3,600 ± 100 yr BP and

4,730 ± 75 yr BP for advanced positions of the Horace Walker and Franz Josef glaciers in South Westland which may correlate with the Meins Knob advances (Table 2).

LYELL AND WHITCOMBE MORAINES

Moraines of the Lyell Glacier younger than those which extend to near the northern end of Meins Knob are grouped into two sets with the names of Lyell and Whitcombe. The youngest set, the Whitcombe moraines, were formed within the last three centuries, and they are discussed in a separate paper (Burrows and Maunder 1975). The Lyell moraines, six or more in number, are completely covered by *Phyllocladus* and *Dracophyllum* scrub. No criteria were available by which the Lyell moraines could be dated absolutely except for the weathering rind thickness of boulders on the youngest of them, Lo.

T. Chinn (pers. comm.) has developed a curve for the time relationship of the weathering rind thickness on exposed greywacke boulders. The modal thickness of the weathering rinds of boulders on the Lo moraine is between 2.0 and 2.5 mm while the rinds on the oldest Whitcombe moraine (M6) are less than 1.0 mm thick. This suggests that the youngest Lyell moraine is considerably older than the oldest Whitcombe moraine and probably more than 1,000 years old (T. Chinn pers. comm.). The M6 moraine is believed to have been formed in the 17th century A.D. (Burrows and Maunder 1975).

There was not time during the course of the field work to undertake a full survey of weathering rind thicknesses on the Rakaia moraines.

A reasonable correlation may be made between the Lyell moraines and the Marquee 2 moraines formed by the Cameron Glacier in the Arrowsmith Range nearby (Burrows 1975). The Marquee 2 moraines lie in a spatially comparable position with respect to the glacier terminus and younger moraines. They also have comparable vegetation and soils, although the Cameron moraines lie at slightly higher altitude and the vegetation has been disturbed by fire. The Marquee 2 moraines began to be formed at least as long ago as the 6th century A.D. and probably some time earlier (Burrows 1975).

Wardle (1973) published a radiocarbon date of 1,510 ± 60 yr BP. for an advance of the Horace Walker glacier in South Westland. The Franz Josef Glacier was also in an advanced position 1,690 ± 60 yr BP (R.P. Goldthwait, *ex* Grant-Taylor and Rafter 1962). The Lyell advances may have been occurring during this period.

The complexity of the glacial history of the last 12,000 years in the Upper Rakaia Valley is comparable with that recorded by Denton and Porter (1970) and Benedict (1973) in the North American Cordillera, or in Europe by Mayr (1964, 1968) and Patzelt and Bortenschlager (1973). Tentative correlations within New Zealand are outlined in Table 2.

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TABLE 2.—Tentative Correlations of Late Otiran-Aranuian Glacial Events.

Stage	Cameron Valley (Burrows 1975)	Age	Rakaia Valley (This paper) (Soons 1963)	Age	Lasman Valley Ben Ohau Range (McGregor 1967)	Mt Cook (Burrows 1973) (Mansergh pers. comm.)	Age	South Westland (Wardle 1973) (Grant-Taylor & Rafter 1962)	Age
Aranuian	Arrowsmith	1930 AD 1413 ± 50 yr AD* > 600 yr BP	Whitcombe	1930 AD at least 400 yr BP	Dun Binnary	Mount Cook	1930 AD 1266 ± 50 yr AD* 800 yr BP	Franz Josef I+	1934 AD at least 400 yr BP
	Marquee 2	prob. > 1000 yr BP	Lyell	prob. > 1000 yr BP	Jacks Stream	Tollogo Hill		Horace Walker I+	at least 1,510 ± 60 yr BP*
								Franz Josef I	1,660 ± 60 yr BP*
	Marquee 1		Mens Knob		Perintosh	Hermitage		Horace Walker II+	2,870 ± 75 yr BP*
								Horace Walker I+	3,660 ± 100 yr BP*
				4,540 ± 105 yr BP*				Franz Josef II+	4,730 ± 75 yr BP*
	Lochaber		Reischek	> 4,540 ± 105 yr BP*					
Late Otiran	Wildman 2	> 9,520 ± 95 yr BP*	Jagged Stream	> 10,000 yr BP*	Birch Hill 2	Birch Hill 2	> 5,120 yr BP*	Waiho Loop 2	
	Wildman 1		Lake Stream	> 11,900 ± 200 yr BP*	Birch Hill 1	Birch Hill 1		Waiho Loop 1	
	Lake Heron		Acheron		Tekapo	Tekapo	> 11,650 ± 200 yr BP*	Kumara 3	13,950 ± 140 yr BP*

*radiocarbon date. +names of glaciers—formal rock-stratigraphic names of glacial phases have not been applied.

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